



**US Army Corps  
of Engineers®**  
Buffalo District

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**FEASIBILITY STUDY REPORT**

**FOR THE GROUNDWATER OPERABLE UNIT**

**LINDE SITE, TONAWANDA, NEW YORK**

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**OCTOBER 2004**

## **EXECUTIVE SUMMARY**

This executive summary provides an overview of the Feasibility Study (FS) report for the groundwater operable unit (OU) at the Linde Formerly Utilized Sites Remedial Action Program (FUSRAP) site in Tonawanda, New York. The FS report was prepared by the U.S. Army Corps of Engineers (USACE) to serve as a principal source of information for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) decision-making for the groundwater at the Linde Site. The FS report describes earlier Linde Site groundwater investigations by the U.S. Department of Energy (DOE) and groundwater investigations at Linde by USACE in 2001 and 2002. Applicable or relevant and appropriate requirements (ARARs) for Linde groundwater are identified. The need for groundwater remediation at Linde is assessed and two alternatives for Linde Site groundwater are identified and evaluated in terms of CERCLA evaluation criteria. The two alternatives identified in this FS report are: (1) A no action alternative, where groundwater is left as is; (2) A limited action alternative, where groundwater will be periodically monitored and land use controls will be established. A comparative evaluation of the options for Linde Site groundwater is then presented in detail.

### **BACKGROUND**

The Linde Site (now owned by Praxair) comprises about 135 acres located at East Park Drive and Woodward Avenue in the Town of Tonawanda. Uranium ore processing was conducted at Linde under a Manhattan Engineer District (MED)/Atomic Energy Commission (AEC) contract in the 1940's. During the uranium ore processing, portions of the property and buildings became contaminated with elevated levels of radionuclides (uranium, radium, and thorium).

Linde was designated as a FUSRAP Site in 1980, and DOE, under its FUSRAP authority at that time, initiated investigations at Linde and the other FUSRAP Sites in Tonawanda: Ashland 1, Ashland 2 and Seaway. A Remedial Investigation (RI) report, Baseline Risk Assessment (BRA), FS report and Proposed Plan (PP) were issued by DOE in 1993, addressing the Tonawanda FUSRAP sites. Following public review, DOE suspended decision-making on the Tonawanda Sites to re-evaluate potential remedial alternatives. In October 1997, responsibility for FUSRAP was transferred to USACE. In March 2000, a CERCLA Record of Decision (ROD) for the Linde Site was signed by USACE and remediation of Linde Site soils and buildings, excluding Building 14 and groundwater, was initiated in June 2000. A ROD for Linde Building 14 was issued by USACE in April 2003. As described above, the FS report for Linde groundwater will serve as a principal source of USACE decision-making on Linde groundwater.

### **LIQUID WASTE DISPOSAL AT LINDE**

During the processing of uranium ore at Linde, liquid waste was produced. The liquids were discharged into storm sewers, sanitary sewers and into the on-site injection wells. From 1944 to 1946, approximately 55 million gallons of liquid wastes were injected under pressure into seven on-site injection wells. The injection wells ranged in depth from 90 to 150 feet and were drilled into bedrock. Approximately 12,000 pounds (lbs) of uranium oxide were discharged to the injection wells; equaling approximately 3 curies (Ci) of natural uranium. The average concentration of natural uranium in the discharge was approximately 14,400 picocuries per liter (pCi/L). An estimated 0.52 Ci of radium were also discharged with the liquid waste.

### **EARLIER GROUNDWATER INVESTIGATIONS AT LINDE**

Groundwater sampling was conducted at Linde for DOE by Argonne National Laboratory (ANL), Oak Ridge Associated Universities (ORAU) and Ford Bacon and Davis Utah (FBDU) in 1981. In 1981, the Aerospace Corporation compiled the results of groundwater sampling at Linde and concluded that the

very high natural mineral content of the groundwater at Linde makes it unacceptable as drinking water or for many other industrial or residential uses and that no significant pathway exists for groundwater exposure to the general public.

DOE also conducted additional groundwater investigations at Linde in the late 1980s – early 1990s as part of the RI of the Tonawanda Site (defined at that time to include the Ashland 1, Ashland 2, Seaway and Linde FUSRAP sites, all located in Tonawanda). In the RI report, BRA, and FS report for the Tonawanda Site, prepared in 1993, it was concluded that the high levels of naturally occurring constituents in Linde groundwater precluded its use for drinking without costly treatment and, in the BRA, it was concluded that there is no significant exposure pathway to Linde groundwater.

### **GROUNDWATER INVESTIGATIONS BY USACE IN 2001 AND 2002**

In the fall of 1997, the responsibility for FUSRAP was transferred to USACE. In March 2000, following review of prior investigations and conducting additional evaluations of site conditions, USACE issued a ROD for the Linde Site. USACE concluded that Linde groundwater presented no significant risks, but based on comments received concerning the adequacy of groundwater sampling, a decision on Linde groundwater was excluded from the ROD.

Following coordination with the U.S. Environmental Protection Agency (USEPA) and the New York State Department of Environmental Conservation (NYSDEC), USACE conducted additional groundwater investigations at Linde in 2001 and 2002.

Three deep and three shallow monitoring wells were installed as part of the 2001 field investigation and groundwater sampling of the new and existing wells was conducted in March and June 2001 and August 2002. Based on the March and June 2001 sampling results, a reduced subset of new and existing deep monitoring wells was selected for sampling in August 2002. Unfiltered samples and filtered samples were analyzed for the presence of radionuclides including radium isotopes, thorium isotopes, uranium isotopes, gross alpha radiation, gross beta radiation and total uranium. Unfiltered and filtered samples from the wells were also analyzed for the presence of target analyte list (TAL) metals. Unfiltered samples from the wells were also analyzed for general chemistry parameters. In March 2001 and August 2002, soil samples were collected for radionuclide analyses and leaching tests.

### **ARARs FOR LINDE GROUNDWATER**

USACE has determined that the USEPA groundwater standards of 40 CFR Part 192, Subpart A are relevant and appropriate to groundwater at the Linde Site. This determination was made based on the similarity of ore processing activities to extract uranium and resulting radionuclides found in the waste after processing at Linde to the activities and wastes found at uranium mill sites where the regulation is applicable. The results of groundwater sampling at the Linde Site in 2001 and 2002 were compared to the 40 CFR Part 192 groundwater standards and analytes exceeding the standards are considered to be contaminants of potential concern (COPCs) for Linde groundwater. The COPCs for Linde groundwater are uranium, molybdenum, chromium and mercury. Gross Alpha is also considered to be a COPC. The 40 CFR Part 192 standards for Linde groundwater COPCs are shown in Table ES-1.

USACE also evaluated the potential for use of the USEPA drinking water standards of 40 CFR Part 141 and the NYSDEC groundwater standards of 6 NYCRR 703 as ARARs for Linde groundwater. USACE concluded that neither the USEPA drinking water standards nor the NYSDEC groundwater standards were ARARs for Linde groundwater, since these standards were set based on the use of the water for drinking. High levels of naturally occurring dissolved solids make Linde groundwater unfit for use without costly treatment.

**Table ES- 1**  
**40 CFR Part 192, Subpart A Groundwater Standards**  
**for Linde Groundwater Contaminants of Potential Concern (COPCs)**

<b>Constituent</b>	<b>Concentration <sup>(1)</sup></b>
Chromium	0.05
Mercury	0.002
Molybdenum	0.1
Combined Radium-226 and Radium-228	5 pCi/L
Combined Uranium-234 and Uranium-238 <sup>(2)</sup>	30 pCi/L
Gross Alpha-particle Activity (excluding radon and uranium)	15 pCi/L

**Notes:**

- (1) Milligrams per liter, unless stated otherwise.
- (2) The regulations state the following: "Where secular equilibrium obtains, this criterion will be satisfied by a concentration of 0.044 milligrams per liter (0.044 mg/L). For conditions other than secular equilibrium, a corresponding value may be derived and applied, based on the measured site-specific ratio of the two isotopes of uranium." The uranium isotopes at Linde are assumed to be in secular equilibrium since the material processed at Linde had not been isotopically enriched or depleted prior to or during processing at the Linde Site.

## **ASSESSMENT OF LINDE GROUNDWATER RESULTS**

As shown in Table ES-2, the results from the August 2002 sampling of the deep wells show the 40 CFR Part 192 groundwater standards, when applied at the specific well locations, instead of the compliance point, the site boundary, were exceeded for uranium in the samples from well LMW-06 and the standard for molybdenum in the samples from wells B29W09D and LMW-06. Well B29W09D is located near the former injection wells in the vicinity of former Buildings 30 and 38. Well LMW-06 is located in the vicinity of the former injection wells near Building 8. Thus, the results of deep groundwater sampling in August 2002 show the 40 CFR Part 192 numeric standards, applied at well locations exceeded only in samples collected from wells in the vicinity of the former injection wells. The August 2002 deep groundwater results are generally consistent with the March 2001 results in terms of the wells showing exceedances of the groundwater standards when applied at specific well locations, although the levels of uranium detected in the samples from LMW-06 (and B29W10D, which is located adjacent to LMW-06) were substantially higher in March 2001. The exception to this is an exceedance (<9% above the standard) of the Ra-226 + Ra-228 standard in the sample from LMW-05 in March 2001. The June 2001 sample results show no exceedances of the uranium standards. Exceedances of the gross alpha standard were detected in the samples from B29W05D, B29W07D and B29W09D in June 2001. Samples from these wells in March 2001 and August 2002 did not show the gross alpha standard exceeded.

As indicated in Table ES-3, the results of the August 2002 sampling of the shallow wells show the uranium standard exceeded (<4% above the standard) in the sample from well LMW-03. The results of the August 2002 sampling are generally consistent with the March 2001 sampling results, both in terms of the exceedance of the uranium standard and uranium levels detected in the samples. The uranium standards were not exceeded in the shallow well samples collected in June 2001. Also as indicated in Table ES-3, the gross alpha standard of 15 pCi/L (excluding uranium), when applied at the specific well location and not the site boundary, was exceeded in the samples collected from shallow well LMW-01 in March and June 2001. However, the gross alpha standards were not exceeded in the shallow well samples collected from LMW-01 in August 2002.

## **CONTAMINANT FATE AND TRANSPORT**

The 1993 RI report concludes that liquid wastes containing radioactive constituents that were injected into the contact zone aquifer at Linde moved under pressure through fractures in the bedrock and into the more permeable contact zone aquifer overlying the bedrock. The RI report further concluded that because the waste was higher in temperature and had a higher pH than the natural groundwater, the radioactive constituents in the waste precipitated to form relatively insoluble solid material within the bedrock fractures and contact zone formation. The RI report then describes the potential for transport of radioactive constituents within the fractured bedrock and contact zone as minimal due to immobility of the constituents, the generally low permeability of the shale, and low hydraulic gradients in these formations. In summary, the RI report concludes that the radionuclides have precipitated in the groundwater and are now immobile in the vicinity of the location where injection occurred.

As detailed in Appendix B, the PHREEQC geochemical model was used to further predict the potential fate of the uranium discharged to the contact zone aquifer at Linde in the 1940s. Site characterization data from the 1993 RI report and findings of the USACE groundwater investigation were used in the modeling. The results of the modeling indicate that the soluble uranium present in the waste could precipitate under the natural conditions in the contact zone aquifer. The modeling predicts that uranium solubility under site conditions is approximately 0.04 mg/L or approximately 27 pCi/L. The evaluation further notes that groundwater monitoring shows high concentrations of uranium in monitoring well sediments and low concentrations of uranium in the groundwater, supporting the premise that uranium is remaining in the solid phase in Linde groundwater.

As further detailed in Appendix B, estimates of the potential transport of uranium in the contact zone aquifer were made using a one-dimensional transport equation. Estimates assumed two cases, a single pulse source of uranium and a solubility-limited source. Based on these estimates, the assessment indicates that uranium should have been observed in monitoring wells during the 55 years since the injection occurred. Because the uranium has not been observed at the levels predicted, it is concluded that the premise is supported that the uranium has low solubility in the contact zone aquifer at Linde. This is consistent with the findings of the 1993 RI report and the premise that due to ionic interaction with subsurface material, the injected radionuclides have lower solubility.

Significantly, the geochemical model indicates that uranium concentrations under Site conditions would be expected to be approximately 27 pCi/L, which is less than the 40 CFR Part 192 standard. Accordingly, notwithstanding the potential transport of uranium that may be occurring, the concentration of uranium is not expected to exceed the standard.

The RI report describes the fate and transport of radionuclides in shallow groundwater in terms of potential horizontal flow with discharge to surface water, with a relatively impermeable layer precluding flow and contaminant transport vertically. No monitoring wells were installed in the shallow aquifer as part of the RI. Therefore, no field evidence of actual groundwater quality in the shallow aquifer was available at the time the RI report was prepared.

The USACE investigations at Linde included the installation of three shallow monitoring wells and three rounds of sampling. The results from one of the shallow wells, LMW-03 showed the U-234+U-238, 40 CFR Part 192 standard of 30 pCi/L exceeded in unfiltered and filtered samples (<15% and 2%, above the standard, respectively) collected in March 2001, not exceeded in the June 2001 samples, and exceeded (<4% above the standard) in the August 2002 samples.

The presence of elevated uranium in the results of analyses of groundwater samples from well LMW-03 indicates that uranium may be leaching from soils in the area. However, despite more than 50 years of precipitation and associated potential for leaching, elevated levels of uranium have persisted in site soils at several locations. The area of LMW-03 is in close proximity to the Building 30 area where active soil remediation was underway at the time of sampling and where soils contaminated with uranium at levels exceeding 10,000 pCi/g were still present at the time of sampling. Accordingly, the sample from LMW-03 would not be representative of post-remediation conditions after soil remediation is complete because soils in the vicinity of LMW-03 had yet to be completely removed (at the time of sampling) to the remedial action criteria for soils established for the Linde Site. It is not likely that the standard will be exceeded in the future after soil remediation is completed.

## **ASSESSMENT OF THE NEED FOR REMEDIATION**

The results of sampling of deep groundwater at Linde show exceedances of the 40 CFR Part 192 numeric standards when applied at the specific well locations. Similarly, in shallow groundwater, the numeric standards of 40 CFR Part 192, Subpart A are met, except for gross alpha at one location and uranium at another location. There is no evidence that the 40 CFR Part 192 groundwater standards are exceeded in deep or shallow groundwater at the point of compliance, the property line. The immediate need for groundwater remediation is not demonstrated. There is, however, no formal means to ensure that Linde groundwater is not inadvertently used as a drinking water source in the future or that environmental conditions change resulting in the radionuclides becoming more mobile and leave the site boundary.

**Table ES-2 - Deep Wells**  
**March 2001, June 2001, and August 2002 Sample Results Exceeding**  
**40 CFR Part 192 Groundwater Standards (1)**

Analyte	Deep Wells - March 2001									Deep Wells - June 2001				Deep Wells - August 2002					
	Ra-226+Ra-228	U-234 + U-238	U-234 + U-238	Uranium (total)	Uranium (total)	Molybdenum	Molybdenum	Chromium	Mercury	Gross Alpha (2)	Gross Alpha (2)	Molybdenum	Molybdenum	U-234 + U-238	U-234 + U-238	Uranium (total)	Uranium (total)	Molybdenum	Molybdenum
40 CFR Part 192 Standard	5 pCi/L	30 pCi/L	30 pCi/L	44 µg/L	44 µg/L	0.1 mg/L	0.1 mg/L	0.05 mg/L	0.002 mg/L	15 pCi/L	15 pCi/L	0.1 mg/L	0.1 mg/L	30 pCi/L	30 pCi/L	44 µg/L	44 µg/L	0.1 mg/L	0.1 mg/L
Preparation	Unf.	Unf.	Fil.	Unf.	Fil.	Unf.	Fil.	Unf.	Unf.	Unf.	Fil.	Unf.	Fil.	Unf.	Fil.	Unf.	Fil.	Unf.	Fil.
Date	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Jun-01	Jun-01	Jun-01	Jun-01	Aug-02	Aug-02	Aug-02	Aug-02	Aug-02	Aug-02
Units	pCi/L	pCi/L	pCi/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	pCi/L	pCi/L	mg/L	mg/L	pCi/L	pCi/L	µg/L	µg/L	mg/L	mg/L
Well																			
B29W05D	1.3	0.89	0.44	1.43	0.52	ND	0.008	0.002	ND	9	27	ND	ND	0.58	0.4	0.106	0.166	ND	ND
B29W07D	1.3	0.18	0.12	0.21	0.09	0.048	0.053	0.002	ND	16	4	0.033	0.053	0.49	0.34	0.731	0.361	0.033	0.036
B29W09D	1.4	1.3	0.78	2.36	1.92	0.44	0.45	ND	ND	52	36	0.42	0.42	1.4	0.37	1.06	0.63	0.33	0.34
B29W10D	1.4	671	332	765	470	0.25	0.24	0.096	0.013	-16	-7	0.22	0.20	NS	NS	NS	NS	NS	NS
LMW-05	5.4	14.9	2.3	26.6	18.1	0.008	0.008	ND	ND	6	1	0.008	ND	5.75	4.32	9.04	7.79	ND	ND
LMW-06	70	544	339	837	390	0.37	0.37	0.004	0.0003	11	2	0.15	0.15	66.1	37.3	98.8	62.9	0.27	0.24

(1) Results exceeding the 40 CFR Part 192 standards are shaded in this table.

(2) Gross  $\alpha$  excluding uranium

ND = Not detected.

NS = Not Sampled

Unf. = Unfiltered sample

Fil. = Filtered sample (0.45 micron filter)

**Table ES-3 - Shallow Wells**  
**March 2001, June 2001, and August 2002 Sample Results Exceeding**  
**40 CFR Part 192 Groundwater Standards (1)**

	Shallow Wells March 2001			Shallow Wells June 2001	Shallow Wells August 2002
Analyte	Gross Alpha (2)	U-234 + U-238	U-234 + U-238	Gross Alpha (2)	U-234 + U-238
40 CFR Part 192 Standard	15 pCi/L	30 pCi/L	30 pCi/L	15 pCi/L	30 pCi/L
Preparation	Fil.	Unf.	Fil.	Fil.	Unf.
Date	Mar-01	Mar-01	Mar-01	June	August
Units	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L
<b>Well</b>					
LMW-01	24.1	0.1	0.01	22.7	12.5
LMW-03	-16	34.5	30.5	-5	31.1

<sup>(1)</sup> Results exceeding the 40 CFR Part 192 pCi/L standards are shaded in this table.

<sup>(2)</sup> Gross  $\alpha$  excluding uranium

Unf. = Unfiltered sample

Fil. = Filtered sample (0.45 micron filter)



## **ALTERNATIVES FOR LINDE GROUNDWATER**

The remedial action alternatives for Linde groundwater are limited because currently the remedial action objective of compliance with ARARs is met based on the August 2002 results. Because ARARs are met and the ARARs are considered protective, and since there is no current or reasonably expected exposure to groundwater, there is no subsequent risk. Thus, the CERCLA threshold criterion of protection of human health and the environment is currently met. However, while the use of on-site shallow or deep groundwater is not envisioned, the numeric thresholds of the 40 CFR Part 192 groundwater standards when applied at the wells are exceeded at some locations on the property, within the property line and, there are no current controls in place to preclude the use of on-site groundwater. Accordingly, USACE considered two alternatives for Linde groundwater. The alternatives considered are:

- No Action. Consideration of a no action alternative is required under CERCLA. Under this alternative site groundwater would be left as is. No monitoring would be conducted.
- Limited Action. Under this alternative, periodic monitoring of site groundwater would be conducted. The analytes to be monitored would be limited to those related to the Site and showing an exceedance of the 40 CFR Part 192 groundwater standards during the 2001 and 2002 groundwater sampling by USACE. A detailed monitoring plan would be developed, with concurrence from NYSDEC and USEPA, that would specify the wells to be monitored, the analytes, the sampling frequencies, and the conditions under which monitoring and specific land use controls could be terminated.<sup>1</sup> Land use controls would be established to preclude the use of site groundwater and would include prohibitions on drilling wells and/or use of any existing wells. At the end of five years, the site conditions would be reviewed to verify that land use controls are effective and ARARs continue to be met. The potential need for subsequent 5-year reviews would also be assessed. If monitoring is no longer required, the need for 5-year reviews could be eliminated.

## **COMPARISON OF ALTERNATIVES**


Table ES-4 summarizes a comparative analysis of the Linde groundwater alternatives in terms of the CERCLA threshold and balancing evaluation criteria.

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<sup>1</sup> The monitoring plan for groundwater would consider statistically based procedures to assess the sampling results under which monitoring could be terminated. Such statistically based procedures are available in USEPA documents such as RCRA Statistical Analysis of Ground Water Monitoring Data (USEPA 530/SW/89/026) and Methods for Evaluating the Attainment of Cleanup Standards, Volume 2: Ground Water (USEPA 230-R-92-014, July 1992).

**Table ES-4 Comparison of Alternatives – Linde Site Groundwater**

CERCLA CRITERION	ALTERNATIVE 1	ALTERNATIVE 2
	NO ACTION	LIMITED ACTION
<b>Overall Protectiveness of Human Health and the Environment</b>	Not considered to be protective of human health and the environment because, while ARARs are currently met, there are no means to ensure that on-site groundwater is not used.	Protective of human health and the environment because ARARs are currently met and monitoring would continue to verify that ARARs continue to be met. Land use controls would prohibit the use of on-site groundwater, eliminating any potential threat to human health associated with the use of on-site groundwater.
<b>Compliance with ARARs</b>	This alternative currently complies with ARARs, but no monitoring would be conducted to ensure that any non-compliance with ARARs is detected should environmental conditions change.	This alternative currently complies with ARARs and monitoring would be conducted to verify that ARARs are met.
<b>Long-Term Effectiveness and Permanence</b>	Not effective and not permanent because there would be no means to ensure that on-site groundwater is not used and no monitoring of potential changes in groundwater quality would be conducted.	This alternative is considered effective and permanent. Land use controls would prohibit the use of on-site groundwater and monitoring would be conducted to ensure that any potential changes in groundwater quality are detected. If it is determined through monitoring that ARARs are exceeded, and additional action is required, such action could be taken.
<b>Short-Term Effectiveness and Environmental Impacts</b>	Effective in the short-term because ARARs are met and no action would be taken that would result in environmental impacts.	Effective in the short-term because ARARs are met and no action would be taken that would result in environmental impacts.
<b>Reduction in Toxicity, Mobility, or Volume Through Treatment</b>	There is no reduction in toxicity, mobility or volume of contaminants associated with this alternative.	There is no reduction in toxicity, mobility or volume of contaminants associated with this alternative.
<b>Implementability</b>	Easily implementable because no action is taken.	Relatively easy to implement. The imposition of land use controls would be moderately complex.
<b>Present Value Cost (\$)</b>	0	\$800,000

  
 WILLIAM E. RYAN III  
 Colonel, Corps of Engineers  
 Acting Division Commander

25 October 2004  
 Date

**FEASIBILITY STUDY REPORT  
FOR THE GROUNDWATER OPERABLE UNIT  
LINDE SITE, TONAWANDA, NEW YORK**

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Appendix B	Geochemical Modeling and Evaluation of Uranium Transport
Appendix C	Real Estate Plan

## ACRONYMS, ABBREVIATIONS AND SYMBOLS

AEC	Atomic Energy Commission
ALARA	As Low As Reasonably Achievable
ANL	Argonne National Laboratory
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
BNI	Bechtel National, Inc.
BRA	Baseline Risk Assessment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
Ci	Curie
cm/s	centimeters/second
COC	contaminant of concern
COPC	contaminant of potential concern
Conrail	Consolidated Rail Corporation
CPS	counts per second
DOE	Department of Energy
ECIDA	Erie County Industrial Development Agency
FS	Feasibility Study
FSP	Field Sampling Plan
ft	foot/feet
FUSRAP	Formerly Utilized Sites Remedial Action Program
g	gram
L	liter
lb(s)	pound(s)
MCLs	Maximum Contaminant Levels
MED	Manhattan Engineer District
m	meters
µg	microgram
µm	micron
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NRC	Nuclear Regulatory Commission
NWI	National Wetlands Inventory
NYCRR	New York Codes, Rules and Regulations
NYSDEC	New York State Department of Environmental Conservation
NYSDOL	New York State Department of Labor
OU	Operable Unit
pCi	picocuries
PP	Proposed Plan
ppm	parts per million
PRB	permeable reactive barrier
QAPP	Quality Assurance Project Plan
Ra	radium
RI	Remedial Investigation
ROD	Record of Decision
SAIC	Science Applications International Corporation
SAP	Sampling and Analysis Plan
SNL	Sandia National Laboratories
TAL	Target Analyte List
TCLP	Toxicity Characteristic Leaching Test

## ACRONYMS, ABBREVIATIONS AND SYMBOLS (continued)

TDS	total dissolved solids
Th	thorium
TPP	technical project planning
U	uranium
UMTRCA	Uranium Mill Tailings Radiation Control Act
U.S.	United States
USBR	United States Bureau of Reclamation
U.S.C.	United States Code
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
WET	Waste Extraction Test
yr	year(s)

**FEASIBILITY STUDY REPORT  
FOR THE GROUNDWATER OPERABLE UNIT  
LINDE SITE, TONAWANDA, NEW YORK**

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## **1. INTRODUCTION**

This Feasibility Study (FS) report was prepared to serve as a principal source for decision-making on groundwater at the Linde Formerly Utilized Sites Remedial Action Program (FUSRAP) Site in Tonawanda, New York. An overview of the Site background and FUSRAP Sites in Tonawanda is presented in this section. In subsequent sections, additional information on Linde groundwater contamination is presented, followed by an evaluation of needs for groundwater remediation and options for Linde groundwater.

### **1.1 Background**

During the early to mid-1940's, portions of the property formerly owned by Linde Air Products Corp., a subsidiary of Union Carbide Industrial Gas (Linde), now owned by Praxair, Inc., in the Town of Tonawanda, New York were used for the separation of uranium ores. The separation processing activities, conducted under a Manhattan Engineer District (MED)/Atomic Energy Commission (AEC) contract, resulted in elevated radionuclide levels in portions of the Linde property. Subsequent disposal and relocation of the processing wastes from the Linde property resulted in elevated levels of radionuclides at three nearby properties in the Town of Tonawanda: the Ashland 1 property; the Seaway property; and the Ashland 2 property. Together, these three (3) properties, with Linde, have been referred to as the Tonawanda Site.

The regional and vicinity locations of the four properties that comprise the Tonawanda Site are shown in Figures 1 and 2. As shown in Figure 2, the Linde Site is located at East Park Drive and Woodward Avenue in Tonawanda.

Under its authority to conduct FUSRAP, the U.S. Department of Energy (DOE) conducted a Remedial Investigation (RI) (BNI 1993), Baseline Risk Assessment (BRA) (DOE 1993a), and FS report (DOE 1993b) for the Tonawanda Site. In November 1993, DOE issued a Proposed Plan (PP) (DOE 1993c) for public comment for the Tonawanda Site, describing the preferred remedial action alternative for disposal of remedial waste and cleanup plans for each of the Tonawanda Site properties. The 1993 PP recommended that remedial wastes from the Tonawanda Site properties be disposed in an engineered on-site disposal facility to be located at Ashland 1, Ashland 2, or Seaway.

Numerous concerns and comments were raised by the community and their representatives regarding the preferred alternative identified in DOE's 1993 PP and the proposed on-site disposal of remedial action waste. In 1994, DOE suspended the decision-making process on the 1993 PP and re-evaluated the alternatives that were proposed.

In October 1997, the Energy and Water Development Appropriations Act for Fiscal Year 1998, PL 105-62, was signed into law, transferring responsibility for the administration and execution of FUSRAP from DOE to the United States Army Corps of Engineers (USACE). The Energy and Water Development Appropriations Act for Fiscal Year 2000, Public Law 106-60, requires that USACE comply with the Comprehensive Environmental Response, Compensation, and Liability Act, 42 United States Code 9601 et seq., as amended (CERCLA), in conducting FUSRAP cleanup work. Therefore, USACE is conducting FUSRAP cleanups in accordance with CERCLA.



## **1.2 Status of the Tonawanda Site Properties**

### **1.2.1 Ashland 1, Ashland 2, and Seaway Area D Sites**

In April 1998, USACE issued a CERCLA Record of Decision (ROD) (USACE 1998) for cleanup of the Ashland 1, Ashland 2, and Seaway Area D properties. Remediation of those properties was initiated by USACE in June 1998.

### **1.2.2 Seaway Site**

Remedies for Seaway Areas A, B and C are being evaluated by USACE in separate CERCLA documentation.

### **1.2.3 Linde Site**

In March 1999, after reviewing the history of the Linde Site and conducting an evaluation of Linde Site information not available in 1993 and potential remedial alternatives, USACE issued a revised PP (USACE 1999a) for cleanup of the Linde Site. A ROD for the Linde Site was issued by USACE in March 2000 (USACE 2000). The ROD excludes CERCLA decision-making on Building 14 and groundwater at the Linde Site. Building 14 is being addressed by USACE in separate CERCLA documentation. Remediation of MED/AEC-related radiological contamination in Linde Site soils and structures in accordance with the March 2000 ROD was initiated in June 2000 and is scheduled for completion in 2007.

In 1992 the DOE designated two properties, the Town of Tonawanda Landfill and the Mudflats Area, into FUSRAP as a Vicinity Property of the Linde Site due to the discovery of materials that appeared to have similar characteristics to MED/AEC materials. USACE is conducting CERCLA studies of these properties and decisions on potential FUSRAP actions will be made in the future. The locations of these properties are shown in Figure 2.

## **1.3 Overview of the March 2000 USACE ROD for the Linde Site**

USACE is remediating soils and buildings at the Linde Site in accordance with the requirements of CERCLA, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), and the CERCLA ROD signed by USACE on March 3, 2000 (USACE 2000).

The March 2000 ROD outlines the remedial actions to be undertaken on portions of the Linde Site by USACE to address soils and structures determined to be radioactively contaminated as a result of uranium processing operations conducted at Linde in the 1940s under an MED/AEC contract. The March 2000 ROD excludes CERCLA decision-making on Building 14 and Site groundwater. Specifically, the March 2000 ROD states, in part, that “the remedy selected...[in the ROD]...does not include Building 14 nor the soils beneath Building 14” and “the final remediation of Building 14 and soils under Building 14 has been excluded from this [March 2000] ROD, to be addressed separately in the future.”

The March 2000 ROD also states “This ROD also does not address the groundwater at the Linde Site. A ROD will be issued in the future that evaluates the Site groundwater and selects any required remedial action” (USACE 2000).

Linde Building 14 and Linde groundwater are referred to, respectively, as the Building 14 Operable Unit (OU) and the Groundwater OU at the Linde Site.<sup>2</sup>

The March 2000 USACE ROD for the Linde Site also states, in part, that the original proposed plan for the Linde (Tonawanda) site (s) [by DOE in 1993] proposed that no action was warranted to address on-site groundwater, that USACE further investigated existing information relating to groundwater, and that the USACE also concluded that no remediation of groundwater is warranted.<sup>3</sup> The March 2000 ROD further notes, however, that “comments received during the comment period expressed concerns about the sufficiency of the samples relied upon in coming to the conclusion that no remediation of the groundwater is warranted.” As described below, additional groundwater investigations were conducted by USACE at Linde in 2001 and 2002.

#### **1.4 Groundwater Investigations Conducted by USACE at Linde in 2001 and 2002**

In March 2000, USACE conducted Technical Project Planning (TPP) meetings with representatives of the New York State Department of Environmental Conservation (NYSDEC), the United States Environmental Protection Agency (USEPA), and other interested parties to develop plans for any supplemental investigations of potential MED-related groundwater contamination at Linde. At the meeting conducted on March 28, 2000 involving NYSDEC, USEPA and USACE, it was agreed that the available geologic and hydrogeologic information was adequate for site characterization, but it was also agreed that additional information was required to address several issues concerning groundwater contamination.

A detailed plan for acquiring the additional information required was subsequently developed, with review by interested parties and USACE approval. The details of the objectives and scope of the additional investigation, including specific field activities, are provided in the January 26, 2001 *Sampling and Analysis Plan – Volume I – Field Sampling Plan (FSP) and Volume II – Quality Assurance Project Plan (QAPP), Linde Groundwater Operable Unit* (USACE 2001). Details of the TPP deliberations and concurrences by NYSDEC and USEPA are provided in the FSP. USACE conducted the field investigations in accordance with the FSP beginning in January 2001. The results of the USACE 2001 investigation of groundwater at the Linde Site are described in the January 2002 report *Results of the 2001 Groundwater Investigation at the Linde Site, Tonawanda, New York* (USACE 2002a).

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<sup>2</sup> The NCP defines an operable unit to mean “a discrete action that comprises an incremental step toward comprehensively addressing site problems. This discrete portion of a remedial response manages migration, or eliminates or mitigates a release, threat of release, or pathway of exposure. The cleanup of the site can be divided into a number of operable units, depending on the complexity of the problems associated with the site. Operable units may address geographical portions of a site, specific site problems, or initial phases of an action, or may consist of any set of actions performed over time that are concurrent but located in different parts of a site.”

<sup>3</sup> The 1993 RI report for the Tonawanda Site (BNI 1993) addresses the Linde, Ashland 1, Ashland 2, and Seaway FUSRAP sites in Tonawanda and notes (page 3-61) that in the Linde area water drawn from the Camillus Shale (the deep groundwater) has high levels of total dissolved solids and salinity that preclude its use for drinking purposes without extensive, costly treatment. In assessing potential pathways for exposure to radionuclides at the Tonawanda Site, the 1993 BRA report (DOE 1993a) concludes (in Section 3.3.4) that a completed groundwater exposure pathway does not exist because groundwater is not potable. The 1993 FS report (DOE 1993b) concluded (page ES-4) that groundwater at the Tonawanda Site was not significantly impacted by MED activities, was not currently or projected to be used as a drinking water source, and remediation of site groundwater was not considered necessary. These documents and the references cited in these documents were reviewed by USACE in concluding, in the March 2000 ROD, that no remediation of groundwater was warranted. As further described in this FS report, additional investigations conducted by USACE at Linde in 2001 and 2002 further confirmed this conclusion.

In May 2002, representatives of NYSDEC and USACE met to discuss NYSDEC comments on USACE's January 2002 report and NYSDEC recommendations for further sampling. It was agreed that additional groundwater sampling and soil sampling for additional leaching tests would be conducted. A June 2002 document, *Sampling and Analysis Plan Addendum (SAP Addendum) Linde Groundwater Operable Unit, Tonawanda, New York* (USACE 2002b), developed by USACE describes the scope of the additional investigation. Additional investigations were conducted in accordance with the SAP Addendum in August 2002. The results of the 2001 and 2002 investigations are provided in the report, *Results of the 2001 and 2002 Groundwater Investigations at the Linde Site, Tonawanda, New York* (USACE 2003).

## **1.5 Purpose and Scope of this Feasibility Study Report**

As described above, this FS report was prepared to serve as a principal source of information for CERCLA decision-making for the Groundwater OU at the Linde Site. Consistent with the ROD for the Linde Site, this FS report focuses on Linde Site groundwater and supplements the information presented in the FS for the Tonawanda Site (DOE 1993b) prepared by DOE in 1993 and the Addendum to the FS report for the Linde Site (USACE 1999b) prepared by USACE in 1999. Brief descriptions of the Linde Site and its history and the circumstances leading to potential for groundwater contamination are presented in this FS report. The results of earlier Linde Site groundwater investigations by DOE and 2001 and 2002 groundwater investigations at Linde by USACE are also summarized.

Remedial action objectives for Linde groundwater are described and applicable or relevant and appropriate requirements (ARARs) are addressed. The need for remediation of Linde groundwater is assessed and alternatives for Linde Site groundwater are identified and evaluated in terms of CERCLA criteria. A comparative evaluation of the options for Linde Site groundwater is then presented.

## **2. LINDE SITE OVERVIEW**

### **2.1 Linde Site Overview**

The Linde Site is now owned by Praxair, Inc. and comprises about 135 acres located at East Park Drive and Woodward Avenue in the Town of Tonawanda. The site is bounded on the north and south by other industrial properties and small businesses, on the east by CSX Corporation (CSX) [formerly Consolidated Rail Corporation (Conrail)] railroad tracks and Niagara Mohawk property and easements, and on the west, by a park owned by Praxair, which is open to the public. In addition, west of the park owned by Praxair, the site is bounded to the west by low density residential area and a school. The regional and vicinity locations of the Linde Site are shown in Figures 1 and 2.

The property contains office buildings, fabrication facilities, warehouse storage areas, material laydown areas, and parking lots. Access to the property is controlled by Praxair. Approximately 1,400 employees work at the Praxair facilities. Figure 3 shows Linde Site locations.

The property is underlain by a series of utility tunnels that interconnect some of the main buildings and by an extensive network of storm and sanitary sewers.

The Linde property is generally flat and it is estimated that approximately half of the Linde plant area is covered with impervious surfaces such as buildings, paved areas and sidewalks; the other half is covered with a packed gravel surface and sod that allows infiltration of precipitation. Several railroad spurs extend onto the property from the CSX property east of the site.

Land uses in proximity to the Linde property include the CSX property, commercial and residential areas to the east, small businesses, light industries, and residential areas to the north, business and industrial areas to the south, and a low density residential area and Holmes Elementary School to the west. Sheridan Park, owned by the Town of Tonawanda's Parks and Recreation Department, is located one-fourth mile to the northwest of the Linde property. Twomile Creek flows through this property. Recreational uses include an 18-hole public golf course, picnicking areas, and playgrounds. Sensitive uses within one mile of the Linde property include five schools, two community buildings, a senior citizens' center, and Kenmore Sisters of Mercy Hospital. The Linde property is fenced and has a buffer zone of grass and trees around the main buildings (DOE 1993a).

## **2.2 Zoning and Future Land Uses**

The Linde Site is currently used for commercial and industrial purposes, and industrial facilities have been present at the site for more than 60 years. As described above, the site is surrounded by industries and small business on three sides and by a park, which is owned by Praxair, on the fourth side.

The Town of Tonawanda has adopted a zoning ordinance that regulates land uses in the Town and zoning districts were established to permit varying degrees of land uses.

The Linde property is located in a Performance Standards Zoning District. The purpose of the Performance Standards District is to encourage and allow the most appropriate use of the land available now as well as approaching future commercial and industrial uses unhampered by restrictive categorizing, thus extending the desirability of flexible zoning, subject to change with changing conditions.

Restrictions in this district permit an institution for human care or treatment or a dwelling unit only if the development abuts a residential zoning district. Other restricted uses include junkyards, waste transfer or disposal, land mining and stockyards. Any proposed uses must follow the acquisition of a Performance Standards use permit. Performance Standards uses are not permitted that exceed New York State regulations or other standards listed in the zoning codes book, such as standards for noise, odor emission, dust emission, and vibrations, as measured at the individual property line.

Zoning in the Linde property vicinity includes a business district to the north, a low-density residential area to the west, and the Performance Standard District to the south and east.

Because the west boundary of the site abuts a residential zone, construction of an institution for human health care or treatment or a dwelling unit are not strictly prohibited under the Performance Standard zoning category. However, given the past and current use of the Linde Site for industrial and commercial uses for more than 60 years, USACE has concluded that the reasonably anticipated future land use of the property will be for industrial/commercial purposes (USACE 2000).

## **2.3 Physical and Environmental Site Characteristics**

The physical and environmental characteristics of the Linde Site are described in detail in the RI report (BNI 1993), the FS report (DOE 1993a), the Addendum to the FS for the Linde Site (USACE 1999a), and the ROD for the Linde Site (USACE 2000). An overview of physical and environmental characteristics of the Linde Site is presented in the following paragraphs.

The Linde Site is relatively flat and is situated on a broad lowland east of Twomile Creek a tributary of the Niagara River. The elevation of the ground surface is approximately 600 ft above mean sea level at the Linde Site (BNI 1993). Twomile Creek begins south of Linde in a natural channel. Near the southern boundary of the Linde site, flow in Twomile Creek is directed into twin subsurface box conduits which

traverse the Linde Site, underground. Stormwater runoff from Linde is collected in the facility's stormwater system and is discharged through two large flow control gates located on the downstream face of the concrete dam that impounds Sheridan Park Lake. Downstream of the Sheridan Park Dam, the natural channel of the Twomile Creek conveys flow in a generally northerly direction to the Niagara River, approximately 2 ¼ miles north of the Linde Site (see Figure 2).

Mapping of regional bedrock geology indicates that the site area is situated on clayey glacial till. Underlying this glacial till is the Camillus Shale of the Salina Group. This formation is approximately 400 feet (ft) thick in the area and consists predominantly of gray, red, and green thin-bedded shale and massive mudstone. Interbedded with the shale and mudstone are relatively thin beds of gypsum, dolomite, and limestone.

Boring logs for eight (8) monitoring wells constructed at Linde during the RI show that bedrock was encountered at depths ranging from approximately 82 to 96 ft (BNI 1993). In borings for the construction of three deep monitoring wells at the Site in 2001, bedrock was encountered at depths ranging from approximately 72 to 85 ft (USACE 2003). The locations of wells installed during the RI and wells installed by USACE in 2001 are shown in Figure 4. Based on numerous soil borings, the RI report indicates that the natural soils at Linde appear to be covered by a fill layer ranging in thickness from 0 to 17 ft. The fill contains substantial quantities of slag and fly ash that was apparently brought on-site from local sources for grading purposes during the construction of the Linde facility (BNI 1993). Undisturbed soils that underlie the site are composed primarily of clay and sandy clay. These soils have low permeabilities precluding significant infiltration of precipitation.

Years of continuous industrial activity at the Linde Site have left only marginal areas for natural plant communities. The property provides minimal urban wildlife habitats, supporting only cosmopolitan species of birds and small animals (DOE 1993b).

No portion of the Linde property is within the 100-year flood zone of Twomile Creek since it is contained in twin box culvert conduits along the western boundary of the property (DOE 1993b).

A review of National Wildlife Inventory (NWI) maps (Tonawanda West and Buffalo Northwest quadrangles) identified no floodplains or wetlands on-site at Linde.

Except for occasional transients, no federally-listed or proposed endangered or threatened species under jurisdiction of the United States Fish and Wildlife Service (USFWS) have been sighted in the project area and no listed or suspected critical habitats occur on the Linde Site (DOE 1993a).

Groundwater conditions at the Linde Site are summarized in Sections 3 and 4, below.

## **2.4 Ongoing Remediation at the Linde Site**

As noted above, remediation of soils and buildings at the Linde Site, in accordance with the 2000 ROD, has been underway since June 2000. The details of the remediation are summarized in Section 2.7 of Appendix A.

When the remedy was selected, USACE determined that the cleanup standards found in 40 CFR Part 192, the standards for cleanup of the uranium mill sites designated under the Uranium Mill Tailings Radiation Control Act (UMTRCA) and the Nuclear Regulatory Commission (NRC) standards for decommissioning of licensed uranium and thorium mills, found in 10 CFR Part 40, Appendix A, Criterion 6(6), are relevant and appropriate for cleanup of MED-related contamination at the Linde Site. The major elements of this remedy involve excavation of soils with contaminants of concern (COCs) (radium, thorium and uranium)

above the soil cleanup levels, placement of clean materials to meet the other criteria of 40 CFR 192, and cleanup of contaminated surfaces in buildings with COCs above the surface cleanup levels.

The selected remedy also involves the demolition of buildings necessary to remediate the site. These buildings include Buildings 57, 67, 73, 73B, 75 and 76, including the building slabs and foundations.

The remediation includes remediation of the adjacent Niagara Mohawk and CSX Corporation (formerly Conrail) properties, where radioactive contamination has already been identified or may be identified as the remediation work is implemented. The remediation is limited to releases that originated from the Linde Site resulting from MED/AEC-related operations. The remediation plan also includes the removal of contaminated sediments from drainlines and sumps and the removal of contaminated soil from a blast wall structure located east of Building 58.

Details of MED/AEC-contamination in Linde soils prior to remediation are summarized in Section 2.6 of Appendix A. Completion of site remediation in accordance with the 2000 ROD is planned in 2007.

### **3. GROUNDWATER AT LINDE AND INJECTION OF MED/AEC WASTES INTO LINDE GROUNDWATER**

Details of groundwater flow characteristics at Linde and detailed descriptions of the injection of MED/AEC wastes into Linde groundwater are provided in Appendix A and in the 1993 RI report. Relevant information is summarized below.

#### **3.1 Site Stratigraphy and Groundwater**

The descriptions of subsurface conditions (both geology and hydrogeology) provided in the 1993 RI report are based on subsurface investigations conducted at the four Tonawanda FUSRAP Site properties, Ashland I, Ashland II, Seaway, and Linde.

The RI report divided the geologic units encountered during drilling activities into the two following categories:

- **Unconsolidated Material.** This refers to the sediments/fill that overlie the bedrock at each of the four sites. In Tonawanda, these units have generally been encountered in the following order from shallowest to deepest: fill, till, varved lacustrine clay, glaciolacustrine deposits, and at the Linde Site, fluvial or glacialfluvial deposits. At the Linde Site, the fluvial or glacialfluvial deposits directly overlie the bedrock.
- **Bedrock.** The bedrock encountered during drilling activities at the four Tonawanda FUSRAP sites is composed of the siltstones, shales, and dolomites of the Silurian Salina Group. The upper 6 to 15 feet of the bedrock “showed moderate to extensive fracturing that in some cases were filled with gypsum”.

To illustrate the relationship between the bedrock and the overlying unconsolidated sediments at the Linde Site, a cross sectional drawing of the subsurface at Linde was developed incorporating subsurface information from the 1993 RI report and information from the investigations conducted at Linde by USACE in 2001. The location of this cross section, referred to as cross section A-A, is shown in Figure 5 and the cross sectional drawing is shown in Figure 6.

In the 1993 RI report, the following three “hydrogeologic systems” were identified based on the results of the investigations conducted at the four Tonawanda FUSRAP sites:

- A **perched zone**, which is defined in the 1993 RI report as occurring within the fill and upper portion of the till. Monitoring wells were not installed in the perched zone during the previous investigations at the four FUSRAP sites (BNI 1993). During the 2001 USACE investigation, the depth of fill encountered during borings for the three shallow wells was minimal and, therefore, the shallow wells installed at Linde in 2001 were not screened in the perched zone. Additional details of the 2001 investigation are described in Section 4.
- A **shallow, semi-confined system** that was encountered at depths ranging from 16 to 40 feet below ground surface (bgs) at the Ashland 1 and 2 sites (BNI 1993). During the 2001 USACE Linde investigation, the shallow semi-confined aquifer was encountered between seven and nine feet bgs in 2001 borings LMW-01, LMW-02, and LMW-03, as shown in Figure 6. The June 2001 piezometric surface for the semi-confined system, as measured in monitoring wells installed at Linde at these locations, is also shown in Figure 6.
- A **contact zone aquifer** that encompasses both basal unconsolidated materials and the underlying fractured weathered bedrock. Prior to the 2001 USACE groundwater investigation, only the contact-zone aquifer was characterized at the Linde Site with the installation of eight contact-zone aquifer monitoring wells. These eight wells are identified as B29W1D, B29W3D, B29W5D, B29W7D, B29W9D, B29W10D, B29W11D, and B29W13D in Figure 4. During the 2001 Linde groundwater investigation, three new monitoring wells were installed in the contact zone aquifer, wells LMW-04, LMW-05, and LMW-06. The piezometric surface for the contact zone aquifer measured in June 2001 in well LMW-06 and existing wells B29W5D and B29W11D, are shown in Figure 6.

For simplification in this report, groundwater in the shallow, semi-confined system is referred to as shallow groundwater. The groundwater in the contact zone aquifer is referred to as deep groundwater.

The RI report indicates that because of the low permeability of the glacial till and clays, very little infiltrating water percolates to the shallow groundwater; therefore, little contaminant transport takes place. Most of the infiltrated water moves horizontally through the relatively higher conductivity top layer [ $1 \times 10^{-3}$  centimeters/second (cm/s)] forming the perched groundwater system. This perched flow is the major subsurface transport mechanism, and according to the RI report, the perched water system is recharged locally and discharges into drainage ditches and creeks. The average distance to a surface discharge point (such as a stormwater drainage ditch) at Linde is approximately 100 ft. At Linde, the average velocity of perched water flow is estimated to be about 33 meters/year (m/yr) [108 feet/year (ft/yr)]. The shallow system is considered to be semi-confined because it is surrounded by silty-clay material that has lower hydraulic conductivity (less than  $10^{-7}$  cm/s) (BNI 1993).

The RI report notes that the hydraulic conductivity of the glaciofluvial deposits overlying the bedrock was not measured at Linde, but groundwater flow in these deposits was assumed to be the same at both Ashland/Seaway and Linde based on similarities in both areas. The RI report further notes that geologic descriptions and gradation analyses suggest that these materials could be described as silty sand.

The RI report estimates that these basal glaciofluvial deposits have a hydraulic conductivity of  $2.3 \times 10^{-3}$  cm/s (2,400 ft/yr) based on published hydraulic conductivity data for silty sand. Using an effective porosity of 0.13 and hydraulic gradient of 0.0003, the average linear groundwater velocity was calculated in the RI report to be 1.7 m/yr (5.5 ft/yr). Piezometric surface maps of the contact-zone aquifer show that there is no significant recharge or discharge for this aquifer at the Tonawanda site (BNI 1993).

At Linde, contaminated effluent was injected directly into the contact zone aquifer. Groundwater flow conditions and adsorption in the rock matrix affect the transport of contaminants in this aquifer (BNI 1993).

The shale underlying the basal glaciofluvial deposits shows moderate to extensive fracturing in the top 6 to 15 feet. The 1993 RI report notes that thirty-five (35) constant-head packer tests were conducted at various depths in Linde bedrock. The results of the hydraulic conductivity estimates, based on the packer tests, are summarized in Table 6 in Appendix A. As shown in Table 6 of Appendix A, twenty-eight (28) of the packer tests at Linde had no water “take” (no water flow through the packer apparatus). The RI report used only the seven (7) packer test results showing water “take” to calculate a geometric mean hydraulic conductivity of  $7.1 \times 10^{-5}$  cm/s (80 ft/yr) for the bedrock at Linde. The 1993 RI report assumed that the upper bedrock is equivalent to a porous medium due to extensive fracturing in this region, and, assuming a porosity of 0.1 percent and a hydraulic gradient of 0.0003, estimated the linear velocity of the groundwater to be 24 ft/yr.

### **3.2 Groundwater Elevations and Groundwater Flow Directions – 2001 and 2002 Investigation**

Groundwater elevations in the eight older wells and the six monitoring wells installed in 2001 were gauged in March and June 2001 prior to sampling. Figures 7 and 8 show the piezometric contours as determined from gauging the deep wells in March and June 2001. Since a complete set of water levels was not collected in August 2002, a piezometric surface map was not constructed for the August 2002 data. The piezometric contours were developed using the SURFER<sup>®</sup> code which assumes a linear relationship between elevation data points and develops contours to simulate points of equal elevations. The contours are illustrative and may not reflect the actual piezometric elevation at points between wells or at more distant points.

The piezometric contours for the contact zone aquifer, as indicated in the figures, show the groundwater flow direction to generally be to the southeast in March 2001 and to the southwest in June 2001. There are some local anomalous readings, such as the difference in elevations in groundwater gauged in wells B29W10D and LMW-06, which are adjacent to one another. (There was a 0.19 ft difference in these elevations in March 2001 and a 0.39 ft difference in these elevations in June 2001. Monitoring wells B29W10D and LMW-06 are screened at different intervals, which may result in variations in groundwater elevations between these monitoring wells.) Overall, the gradients across the site are small. For example, the water level elevation difference between well B29W07D and B29W05D, located about 2,150 ft southwest, was 0.49 ft in June 2001, or a gradient of 0.0002. The June 2001 groundwater flow direction and gradient information for the deep aquifer determined during the 2001 investigation are generally consistent with the information reported in the 1993 RI report, which indicates that flow in the deep aquifer is to the southwest. The March 2001 flow direction data appears to be anomalous. Groundwater elevation measurements were made in several of the deep wells prior to sampling in August 2002. As in the earlier measurement in 2001, groundwater elevation differences across the Site were small. No changes to the conclusions on groundwater flow direction were made based on the 2002 measurements.

The groundwater elevations observed in the contact zone aquifer are also consistent with the findings of the RI report that the contact zone aquifer is under confined conditions, with the hydraulic head rising 40 to 55 ft above the contact zone.

#### **3.2.1 Shallow Wells**

Groundwater elevation data are limited for the shallow wells. The reported groundwater elevations show elevations in the shallow wells 25-30 ft above the elevations for the deep wells in the contact zone



aquifer, which is consistent with the presence of a low conductivity layer separating the shallow and deep systems, as reported in the RI report.

### **3.3 Overview of Uranium Ore Processing and Effluent Disposal at Linde in the 1940's**

Details of ore processing and effluent disposal at Linde are provided in Sections 2.2 through 2.4 of Appendix A and are summarized below.

As described in the RI report, uranium ore processing was conducted at Linde under an MED/AEC contract in the 1940's. A three-step process was used to separate uranium from the uranium ores and tailings: in Step I ores and occasional residues (from Step II operations and other MED/AEC processes) were processed to produce uranium oxide; in Step II, uranium oxide was converted to uranium dioxide; in Step III, uranium dioxide was converted to uranium tetrafluoride. Residues from Steps II and III were recycled, whereas Step I produced large amounts of liquid and solid residue. The liquids were discharged into storm sewers, sanitary sewers and into the on-site injection wells.

In April 1944, the company, with approval from MED, began disposing of the liquid wastes in on-site wells. From 1944 to 1946, seven on-site wells were used during various periods of time for disposal of the liquid wastes. Available information suggests that from time to time the wells would plug, overflow, and have to be cleaned or replaced.

The seven wells were located in two main areas: three wells located in the area of Plant No. 1 (present Building 8) and four wells located near the Ceramics Plant (the former Buildings 30 and 38). The locations of the former injection wells are shown in Figure 4. It is reported that the injection wells ranged from approximately 90 to 150 ft in depth and were drilled into bedrock. Neither the 1993 RI report nor other reports provide information on the volumes of effluent that were discharged to each of the individual injection wells but the RI report indicates that the total estimated volume of effluent discharged into the injection wells was approximately 55 million gallons.

Information available in 1981 indicates that the filtrate discharged into the sewer or wells was a high pH solution (above a pH of 10) consisting mainly of ions from excess sodium sulfate, sodium carbonate, and sodium hydroxide. In addition, some chloride ions from the barium chlorides added to enhance radium recovery would also have been present, along with a small amount of a variety of complex anions of the many minor elements such as vanadium, nickel and cobalt. Small concentrations of uranium and radium were also present (Aerospace 1981).

The weekly averages of uranium oxide concentrations in the effluents analyzed from April 1944 to July 1946 (from progress reports) ranged between 0.011 and 0.064 grams per liter (g/L). As further detailed in Appendix A, it was estimated that approximately 12,000 pounds (lbs) of uranium oxide were discharged to the injection wells. The 1981 Aerospace report, the principal source of information on the injection of MED/AEC waste at Linde, estimates that approximately 3 curies (Ci) of natural uranium were discharged to the subsurface at Linde. While not specifically calculated in the Aerospace report, using these estimates and the estimated 55 million gallons of wastes discharged, the average concentration of natural uranium in the liquid wastes discharged to the subsurface would have been approximately 14,400 picocuries per liter (pCi/L).

The 1981 Aerospace report (Aerospace 1981) states that only limited data are available regarding the radium concentrations in the effluent injected. As described in greater detail in Appendix A, based on a reported average radium concentration of  $2.5 \times 10^3$  picocuries per liter (pCi/L) in the waste, it was estimated that about 0.52 Ci, or about 0.5 grams, of radium was discharged to the injection wells at Linde.

### **3.4 Contaminant Fate and Transport in Deep Groundwater**

#### **3.4.1 Overview of Findings and Conclusions on Contaminant Fate and Transport in Deep Groundwater as Described in the 1993 RI Report**

The findings and conclusions concerning the fate and transport of wastes injected into deep groundwater at Linde, as reported in the 1993 RI report, are detailed in Section 3.1 of Appendix A and summarized below.

As described above, the RI report indicates that approximately 55 million gallons of liquid waste effluent, containing approximately 12,000 lbs of dissolved uranium oxide, was injected into the subsurface at Linde in the 1940s. The RI report states that this effluent, which contained primarily ions of sodium, sulfate, sodium carbonate, sodium bicarbonate, and chloride, was injected at a temperature of approximately 60°C (140°F). Minor concentrations of vanadium, cobalt, nickel, molybdenum, uranium, and radium were also present in the effluent. This liquid had a pH above 10 and a total dissolved solids (TDS) concentration greater than 20,000 parts per million (ppm). The RI report notes natural formation water in the bedrock units contains significantly lower concentrations of the major ions and TDS; the water temperature is 12°C (54°F); and the pH is approximately neutral (7.0 to 7.5).

Based on the above scenario, the RI report concludes that the nature of the subsurface contamination is probably in the form of mineral precipitates of uranyl sulfates and carbonates in the fractures and pore space of the Salina Group shale. The RI report notes that groundwater in the shale in the immediate proximity of the property exhibits elevated concentrations of sodium, sulfate, and chlorides and has a higher pH (9+) than the natural formation water and further notes that the generally low permeability of the shale and the computed flow velocities indicate that no significant migration of the contaminants from the immediate area has occurred.

Based on the findings of the RI, the RI report concludes that contamination in the contact zone (deep) aquifer is from well effluents at Linde and only very soluble metals such as molybdenum were detected in this aquifer.

### **3.5 Contaminant Fate and Transport in the Perched and Shallow Groundwater as Described in the 1993 RI Report**

The details of contaminant fate and transport in the perched and shallow groundwater at Linde, as described in the 1993 RI report, are provided in Section 3.2 of Appendix A and summarized below.

The RI report notes that Linde is generally covered by a thin veneer of coarse-grained fill material (0 to 4 ft thick) with localized pits and old building foundations that contain fill to depths as great as 17 ft and that undisturbed sediments that underlie the surface fill material are composed primarily of clay and sandy clay. The RI report observes that these soils have low permeability, which precludes infiltration of significant quantities of precipitation, and that infiltrating water (perched zone) tends to flow laterally along the contact surface of the undisturbed sediments in the fill material and discharges into streams and wetlands where the natural clay materials are at the surface. Subsurface ponding occurs in the buried pits and old building foundations containing fill material. Water trapped in these areas will percolate downward at a slow rate because of the low permeability of the underlying clays. Flow directions in the fill material generally correspond to the surface topographic configuration. No monitoring wells were installed at Linde during the RI to determine water quality in either the perched or the shallow groundwater. As described below, shallow groundwater monitoring wells were installed by USACE at Linde in 2001.

The RI report states that the primary pathway of contaminant transport through subsurface soil is via the perched groundwater system. Because of the natural clays underlying the properties, vertical percolation of recharge water to the shallow groundwater system is minimal; therefore, the potential for contaminant migration to the shallow groundwater system is reduced. The RI report indicates that water infiltrating through the contaminated soils may leach contaminants and transport them to the perched groundwater system. The perched system, which follows the contour of the top of the natural clays, transports the contaminants to nearby discharge points in the surface drainage systems. The RI report indicates, however, that sampling of surface water at locations upstream and downstream of the Linde Site was conducted during site characterization activities in 1988 and 1989. The results of the sampling show surface water was not impacted by radionuclides from the Site, when upstream and downstream results are compared. These samples were taken prior to the remediation of soils that has been underway at Linde since 2000, removing hundreds of tons of soil contaminated with radionuclides and greatly reducing any potential leaching of radionuclides to groundwater or contaminant discharge to surface water.

The RI report concludes that the results do not indicate that the MED/AEC-related radionuclides and metals are migrating at a detectable rate into the natural clays below the property. However, removal of the source term as a result of the remedial actions for soils serves to all but eliminate this migration pathway.

#### **4. SUMMARY OF FINDINGS OF LINDE GROUNDWATER INVESTIGATIONS BY USACE IN 2001 AND 2002**

As described in Section 1.3, earlier reports that addressed the Linde Site, including the 1993 RI report (BNI 1993), the 1993 BRA (DOE 1993a) and the 1993 FS report (DOE 1993b), had concluded that no remedial action was warranted for Linde groundwater. The 2000 USACE ROD for the Linde Site (USACE 2000) also concluded that no remedial action is warranted for Linde groundwater. This conclusion was based on evaluation of the earlier reports, including the 1993 BRA, which concluded that a completed exposure pathway does not exist for groundwater at the Tonawanda FUSRAP Sites because groundwater is not potable (DOE 1993a). The investigations of Linde groundwater in 2001 and 2002 were conducted by USACE to supplement the information available in 1993 and address data gaps identified during meetings with agency representatives.

The principal investigation activities in 2001 included:

- construction of 3 new deep monitoring wells and the construction of 3 new shallow monitoring wells;
- two groundwater sampling rounds (March and June, 2001), with sampling conducted at the new and existing monitoring wells;
- analyses of filtered [with a 0.45 micron ( $\mu\text{m}$ ) filter] and unfiltered groundwater samples from these wells for the presence of radionuclides and metals, and also analyses of unfiltered samples from these wells for general chemistry parameters; and
- collection of soil samples for radionuclide analyses and leaching tests.

The principal investigation activities conducted in 2002 included:

- a groundwater sampling round (August 2002), with sampling conducted at the new monitoring wells constructed by USACE in 2001 and selected older monitoring wells that were constructed by DOE;

- analysis of filtered and unfiltered groundwater samples from these wells for the presence of radionuclides and metals; and
- collection of soil samples for radionuclide analyses and leaching tests.

The investigations conducted and their findings are briefly summarized in the following sections. Additional details are provided in the USACE report, *Results of the 2001 and 2002 Groundwater Investigations at the Linde Site* (USACE 2003).

#### **4.1 Description of the Field Investigations in 2001**

##### **4.1.1 Investigation to Assess Deep Groundwater - Deep Monitoring Wells**

Three deep monitoring wells were installed as part of the 2001 field investigation. New monitoring well LMW-06 is located near Building 8 in the vicinity of the former injection wells near Building 8 and in close proximity to boring L1WRO-01, which was drilled as part of the second phase of the DOE RI (1990-1991). The 1993 DOE RI report notes that elevated gamma readings were noted in this boring (L1WRO-01), which was located about one ft from a former injection well and a yellow precipitate was observed from a thin fracture of the bedrock core from this boring. This precipitate was encountered at a depth of approximately 100 feet during the RI. During the boring for new well LMW-06 in 2001, it was planned that an attempt would be made to obtain a sample of this precipitate and test the sample to determine the potential for leaching of the material into groundwater. During the boring for new well LMW-06 in February 2001, this yellow precipitate was not observed and no samples were retrieved for leaching tests.

Based on information in the 1993 RI report and measurements by USACE in March 2000, it was determined that the groundwater flow direction in the contact (deep) zone aquifer at the site is generally southwesterly. USACE reviewed site conditions and the locations of the existing deep monitoring wells and determined, in concurrence with NYSDEC and USEPA representatives, that two additional deep monitoring wells, LMW-05 and LMW-04, in addition to new well LMW-06, were required to better assess whether MED-related constituents in the injected effluent have had an unacceptable impact on water quality.

New deep monitoring well LMW-05 is located approximately 1,800 ft southwest of the former injection wells near former Buildings 30 and 38. New deep monitoring well LMW-04 is located approximately 1,300 feet southwest of the former injection wells near Building 8. The locations of the three new deep monitoring wells installed in 2001, LMW-04, LMW-05, and LMW-06, are shown in Figure 4.

##### **4.1.2 Investigations in 2001 to Assess Potential Impacts to Shallow Groundwater**

Shallow groundwater at the Linde Site is separated from the deep, contact zone groundwater by a thick layer of till and clay. No monitoring wells were installed during the RI by DOE to monitor shallow groundwater at Linde and no shallow groundwater elevation data were available prior to investigations conducted by USACE in 2001. Information in the 1993 RI report indicates, however, that shallow groundwater flow is presumed to flow laterally with topography toward natural or manmade surface water drainage ways present at the Site.

To assess the potential for impacts to shallow groundwater, leaching tests and groundwater investigations were conducted as described below.

#### **4.1.2.1 Soil Sampling and Leaching Tests – 2001 Investigations**

Samples of the site soil during on-going soil remedial activities were collected in March 2001 and subjected to leaching tests to determine the potential impacts to shallow groundwater. The soil samples were analyzed for total activity of uranium, radium, and thorium isotopes and also subjected to a modified California Waste Extraction Test (WET), which is similar to the Toxicity Characterization Leaching Procedure (TCLP) test, using an organic acid leaching solution. The results of the analysis of the radionuclide concentrations in the soil and in the final extract solutions allow for a direct comparison between total and leachable activities (concentrations) providing an indication of the potential for contaminant mobility. Section 4.4, below, describes the results of the leaching tests.

#### **4.1.2.2 Shallow Monitoring Wells – 2001 Investigations**

Three shallow monitoring wells were installed as part of the field investigation: LMW-01, LMW-02 and LMW-03. Borings were advanced to depths of 20 to 25 feet and the wells were installed with 10 ft screens. Subsurface conditions at the locations of these shallow wells are shown in Figure 6.

These wells were sampled as part of the 2001 investigation. (Note: No groundwater samples were taken from LMW-02 due to slow recharge.) The locations of the three shallow monitoring wells installed in 2001, LMW-01, LMW-02, and LMW-03, are shown in Figure 4.

#### **4.1.3 Downhole Gamma Scans – 2001 Investigations**

After the new monitoring wells were installed, downhole gamma scanning was performed in the six new and the eight existing monitoring wells installed during the RI. These scans were conducted to assess the potential that radioactively contaminated material injected into the subsurface may be present at the strata where deep wells were constructed and to assess the potential for the presence of radioactive material in the till above the clay strata at the shallow well locations. The downhole scans produced results in counts per second (CPS) and may identify elevated levels of gamma-emitting radionuclides but can not be used to identify specific radionuclide constituents. At well LMW-06, elevated gamma levels were seen at approximately 89.9 ft below the ground surface, approximately at the depth where the underlying bedrock begins. Elevated gamma readings were also observed in well B29W-10D, located about 4 ft from well LMW-06. The elevated readings in B29W-10D were seen at a depth of approximately 96 ft. Elevated gamma readings were not observed in the deep subsurface at other site locations. It was concluded that the elevated gamma measurements in wells LMW-06 and B29W-10D may correspond to either radioactively impacted groundwater or geologic materials impacted by their injection. Wells LMW-04 and LMW-05 showed increased average gamma radiation in the shallower subsurface at depths of 42-63 ft and 35-44 ft, respectively. These increased gamma elevations were attributed to geologic variations and the presence of increased clay material. Three wells (LMW-01, LMW-02 and LMW-03) exhibited elevated gamma activity very near to the surface (2 to 6 ft below ground surface). These zones are interpreted to represent radioactively impacted soils, which are being remediated at Linde.

The details of the downhole gamma scans are available in the report entitled *Borehole Geophysical Survey Report at the Linde FUSRAP Site, Tonawanda, New York* (SAIC 2002).

#### **4.1.4 Groundwater Sampling and Analyses – 2001 Investigations**

Groundwater samples were collected from five of the six newly installed monitoring wells and the eight existing monitoring wells in March and June 2001 (LMW-02 was not sampled in March and June 2001 due to slow recharge). Unfiltered samples and filtered samples were analyzed for the presence of radionuclides including radium isotopes, thorium isotopes, uranium isotopes, gross alpha radiation, gross beta radiation and total uranium. Unfiltered and filtered samples from the wells were also analyzed for the presence of target analyte list (TAL) metals. Unfiltered samples from the wells were also analyzed for general chemistry parameters.

#### **4.2 Groundwater Investigations in 2002**

The groundwater investigations at Linde in 2002 included groundwater sampling and analyses, the analysis of soil samples and soil sample leaching tests as described in the following sections.

##### **4.2.1 Groundwater Sampling and Analyses in 2002**

In August 2002, groundwater samples were collected from five of the six monitoring wells that were installed at Linde by USACE in 2001 (shallow wells LMW-01 and LMW-03, and deep wells LMW-04, LMW-05, and LMW-06), and three of the previously installed monitoring wells (deep wells B29W05D, B29W07D, and B29W09D). The locations of these monitoring wells are shown in Figure 4. Sampling and analyses of the groundwater samples was conducted in accordance with the SAP (USACE 2001), and the SAP Addendum (USACE 2002b). Like the previous two sampling rounds (March and June 2001), insufficient groundwater recharge precluded the sampling of well LMW-02 in August 2002.

As described in the SAP Addendum (USACE 2002b), the eight (8) monitoring wells sampled in August 2002 were selected for sampling based on previous analytical results.<sup>4</sup>

Unfiltered samples and filtered samples were analyzed for the presence of radionuclides including radium isotopes, thorium isotopes, uranium isotopes, gross alpha radiation, gross beta radiation and total uranium. In addition, unfiltered and filtered samples from the wells were analyzed for the presence of TAL metals and boron and molybdenum.

##### **4.2.2 Soil Sampling and Leaching Tests – 2002 Investigation**

As in the investigations conducted in 2001, several samples of site soils were collected at the Linde Site in August 2002 and subjected to leaching tests. These tests were conducted to determine potential impacts to shallow groundwater. The results of leaching tests are described in Section 4.4.

#### **4.3 Assessment of Groundwater Results**

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<sup>4</sup> The wells sampled in August 2002 were those that were selected for sampling in the SAP Addendum (USACE 2002b) in coordination with NYSDEC and USEPA. As described in the SAP Addendum, the wells that were selected were those that had shown one or more exceedances of the 40 CFR Part 192 groundwater standards during either the March 2001 or June 2001 sampling rounds. The exceptions to this were: well LMW-04 which has shown no exceedances of the standards, but was included in the 2002 sampling because it is located along the downgradient, southern boundary of the Linde Site; and well B29W10D, which had shown exceedances of the standards in 2001, but was not included in the 2002 sampling because monitoring well LMW-06 is in close proximity to this well (laterally and vertically) and samples from B29W10 had shown results similar to LMW-06 results in both the March and June 2001 sampling rounds.

The results of the groundwater sampling at Linde in 2001 and 2002 are included in Tables 10 through 25 in Appendix A.

The results of the 2001 and 2002 groundwater sampling were compared to the groundwater standards found in 40 CFR Part 192, which are applicable to specific sites designated under UMTRCA.

The comparison of the groundwater results to 40 CFR Part 192 groundwater standards was conducted to identify contaminants of potential concern (COPCs) for site groundwater and, as further described in Section 5, to assess groundwater quality in terms of ARARs. The 40 CFR Part 192 standards for the Linde groundwater COPCs are shown in Table 1.

#### **4.3.1 Gross Alpha Results**

As shown in the shaded cells in Tables 2 and 3, the gross alpha standard of 15 pCi/L was exceeded in the June 2001 samples from deep wells B29W05D, B29W07D and B29W09D and in samples from shallow well LMW-01 collected in March 2001 and June 2001. The maximum gross alpha level reported was 52 pCi/L in a sample from deep well B29W09D, which is near the former injection wells in the vicinity of former Buildings 30 and 38. None of the August 2002 samples showed gross alpha levels exceeding the standard.

#### **4.3.2 Radium, Uranium, Molybdenum, Chromium, and Mercury**

As indicated in Table 2, the Ra-226+Ra-228 standard is exceeded (<9% above the standard) in deep well LMW-05 and is exceeded in LMW-06, in the unfiltered samples collected in March 2001. The Ra-226+Ra-228 standard is not exceeded in any of the samples collected in June 2001 or August 2002.

The uranium standard of 30 pCi/L is the sum of the U-234 and U-238 and, as noted in Table 1, the total uranium standard is equivalent to 0.044 milligrams per liter (mg/L).<sup>5</sup>

As shown in Table 2, the U-234 + U-238 standard (30 pCi/L) is exceeded in the unfiltered and filtered samples collected from deep wells B29W10D and LMW-06 in March 2001 and in LMW-06 in August 2002. Similarly, the total uranium standard [44 micrograms per liter (µg/L) based on mass] is also exceeded in the unfiltered and filtered samples from these wells in March. The uranium standards were not exceeded in any samples collected in June 2001.

As also shown in Table 3, the U-234 + U-238 standard of 30 pCi/L is exceeded in the unfiltered and filtered samples (<15% and 2% above the standard, respectively) collected from shallow well LMW-03 in March 2001 and in the unfiltered sample from LMW-03 in August 2002. The total uranium standard of 44 µg/L is not exceeded in samples from the shallow wells.

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<sup>5</sup> Table 1 is based on Table 1 of 40 CFR Part 192, Subpart A. As shown in Table 1, the combined uranium-234 and uranium-238 standard of 30 pCi/L (on an activity basis) is satisfied on a mass basis if the mass concentration is less than 0.044 milligrams per liter (mg/L) where secular equilibrium is assumed. The uranium isotopes at Linde are assumed to be in secular equilibrium since the material processed at Linde had not been isotopically enriched or depleted prior to receipt or during processing at the Linde Site. Comparison of the Linde groundwater results to the uranium standard based on mass is preferable to comparison to the standard based on activity because of the error inherent in the measurement of radionuclide activities and assumptions concerning the conversion of mass concentrations to activity concentrations. However, in the assessment described herein, comparisons are made to both the activity concentration standards and the mass concentration standards.

The molybdenum standard of 0.1 mg/L is exceeded in samples from several of the deep wells in 2001 and 2002. As shown in Table 2, the maximum molybdenum concentration detected is 0.45 mg/L in well B29W09D in March 2001.

The chromium concentration of 0.096 mg/L exceeds the chromium standard of 0.05 mg/L and the mercury concentration of 0.013 mg/L exceeds the mercury standard of 0.002 mg/L in the unfiltered sample collected from well B29W10D in March 2001. The chromium and mercury standards are not exceeded in any other sample collected in 2001 or 2002.

#### **4.3.3 Groundwater Assessment Summary**

The results from the August 2002 sampling of the deep wells show the 40 CFR Part 192 groundwater standards exceeded for uranium in the samples from well LMW-06 and the standard for molybdenum in the samples from wells B29W09D and LMW-06. Well B29W09D is located near the former injection wells in the vicinity of former Buildings 30 and 38. Well LMW-06 is located in the vicinity of the former injection wells near Building 8. Thus, the results of deep groundwater sampling in August 2002 show the 40 CFR 192 standards exceeded only in samples collected from wells in the vicinity of the former injection wells. The August 2002 deep groundwater results are generally consistent with the March 2001 results in terms of the wells showing exceedances of the groundwater standards, although the levels of uranium detected in the samples from LMW-06 (and B29W10D, which is located adjacent to LMW-06) were substantially higher in March 2001. The exception to this is an exceedance (<9% above the standard) of the Ra-226 + Ra-228 standard in the sample from LMW-05 in March 2001. The June 2001 sample results show no exceedances of the uranium standards. Exceedances of the gross alpha standard were detected in the samples from B29W05D in June 2001. Samples from these wells in March 2001 and August 2002 did not show the gross alpha standards exceeded.

The results of the August 2002 sampling of the shallow wells show the uranium standard exceeded (<4% above the standard) in the sample from well LMW-03. The results of the August 2002 sampling are generally consistent with the March 2001 sampling results, both in terms of the exceedance of the uranium standard and uranium levels detected in the samples. The uranium standards were not exceeded in the shallow well samples collected in June 2001.

The 40 CFR Part 192 groundwater analytes exceeding the 40 CFR Part 192 groundwater standards are considered to be COPCs in Linde groundwater. Based on the 2001 and 2002 groundwater sampling, the COPCs for Linde groundwater are: radium, uranium, molybdenum, chromium, and mercury. Gross alpha is also considered to be a COPC.

#### **4.3.4 Variation in Groundwater Sample Results - March and June 2001 and August 2002**

The March 2001 and June 2001 sample results show substantial variation in the case of uranium at two locations and in the radium at one location. In some cases, the variation is one to two orders of magnitude. As examples, the total uranium in the unfiltered sample from LMW-06 in March 2001 unfiltered sample is 837 µg/L, while the total uranium in the unfiltered sample from the LMW-06 in June 2001 is 17.9 µg/L (see Table 12 in Appendix A). The results from the August 2002 sample round generally show a continuing downward or steady trend, for all analytes except uranium (isotopic and total). In August 2002, the total uranium concentration in LMW-06 was 98.8 µg/L, compared to 17.9 µg/L in June 2001 in the unfiltered sample. A similar trend is observed in the filtered samples and in the results of the metals analyses.

In the deep wells, exceedances of the uranium and radium standards are seen only in the new wells, LMW-06 and LMW-05, and in older well B29W10D, which is immediately adjacent (less than 4 ft) to



new well LMW-06. The new wells were installed using a Rotosonic® drill, which imparts high energy levels to the formation as drilling occurs through vibration, rotation, and downward pressures. It is believed that the high energy transmitted locally to the formation resulted in a temporary mobilization of the immobilized residues present in the formation near the injection wells as the drilling proceeded. In the first sampling round in March 2001, the mobilized residues containing radionuclides were still present and the results of the analyses reflected elevated levels of radionuclides, most notably, uranium.

There are numerous variables, both environmental and analytical, that may contribute to variations in the results. Some of the environmental variables would include variations in precipitation (i.e., high spring rainfall and recharge versus late summer conditions with negligible recharge), purging and sampling methods. The analytical results could vary for samples with the same actual concentrations, but different results obtained [e.g., a small speck of radiological material (submicron size) passing through a filter could result in a much higher pCi/L concentration.]

#### **4.4 Results of Leaching Tests**

##### **4.4.1 Leaching Tests Conducted During Investigations in 2001**

Five (5) soil samples (and one duplicate sample) were collected at the Linde Site on March 8 and 9, 2001. Two samples and one duplicate sample were collected from below the footprint of Building 30. Three samples were collected at a depth of 0.5 to 1.5 ft from an excavation near Building 73B.

These soil samples were subjected to the WET extractions to assess the potential for leaching. The WET test is aggressive and represents a worst case for leaching. The results (see Table 28 in Appendix A) found that the soils near Building 30, where various forms of the MED materials could be found (e.g., ore, residues, processed materials, uranium product, etc.), demonstrated that more of the uranium would leach from the soil than would from the soils around Building 73B under these aggressive conditions. The 2001 shallow groundwater results near Building 30 (LMW-03) show elevated levels of uranium whereas the results near Building 73B (LMW-01) do not (see Table 27 in Appendix A). In both cases, the groundwater concentrations are much less than the leachate results from the WET extraction, which is expected, and better represents the potential for leaching under current site conditions. The actual groundwater concentrations of uranium are at levels below the 40 CFR Part 192, Subpart A standards, for both wells in the June 2001 groundwater samples and only well LMW-03 exceeded the criteria (<4% above the standard) in the March 2001 groundwater samples. Both the WET extraction results and the groundwater sampling results support the conclusion that there is some potential for leaching of radionuclides (uranium) from site soils currently being remediated under a separate CERCLA action.

##### **4.4.2 Leaching Tests Conducted During Investigations in 2002**

Four (4) soil samples (and one duplicate sample) were collected at the Linde Site in August 2002. Two samples and one duplicate sample were collected from below the footprint of Building 30, in an area (Class 1 area) where active soil remediation activities (soil removal) have occurred or were ongoing by USACE. Two additional soil samples were collected from Class 2 areas, where soil remediation is not planned, located along the northern property line and east of Building 90 (The definitions of Class 1 and Class 2 soil areas at Linde and further details of soil sampling are provided in Section 4.4.1.2 of Appendix A).

The samples were analyzed for isotopic radium, thorium, and uranium. The samples were also subjected to the CAL WET (using an extraction fluid of pH 5) and modified-WET extractions (using an extraction fluid pH of 7.95, which is an average of the actual pH measured in Site shallow groundwater in 2001 and 2002). (Refer to Appendix A for details.)

Soils subjected to the CAL WET extractions show the potential for leaching. Samples subjected to the modified CAL WET show significantly less leaching potential (see Table 28 in Appendix A).

The leaching test results suggest that there is potential for leaching of radionuclides (uranium) from site soils. It is noted, however, that actual shallow groundwater concentrations of uranium are at levels above (<2% to 15% above the standard) or below the 40 CFR Part 192, Subpart A standards. As reported in the 1993 RI report, there were no elevated levels detected in the surface water samples collected from Twomile Creek.

Given the extensive excavation and removal from the Site of soil containing elevated levels of uranium and other radionuclides, potential sources of leaching of radionuclides to shallow groundwater are now greatly reduced and exceedances of the 40 CFR Part 192, Subpart A groundwater standards are not expected.

#### **4.5 Conceptual Model of Contaminant Fate and Transport Based on Current Information**

##### **4.5.1 Contact Zone Aquifer**

The RI report concludes that liquid wastes containing radioactive constituents were injected into the subsurface in the 1940s and after injection moved under pressure through fractures in the bedrock and into the more permeable contact zone aquifer overlying the bedrock. The RI report further concluded that because the waste was higher in temperature and had a higher pH than the natural groundwater, the radioactive constituents in the waste precipitated to form relatively insoluble solid material within the bedrock fractures and contact zone formation. The RI report then describes the potential for transport of radioactive constituents within the fractured bedrock and contact zone as minimal due to immobility of the constituents and low hydraulic gradients in these formations. In summary, the RI report concludes that the radionuclides have precipitated in the groundwater and are now immobile in the vicinity of the location where injection occurred. In the RI report, the field evidence of the conceptual model for the fate and transport of the injected radioactive constituents in the contact zone aquifer was limited, with only one set of validated groundwater sample results from one well (B29W10D) on one date.

The 2001 and 2002 field investigations at Linde included the construction of three new deep wells to monitor groundwater quality in the deep aquifer and three rounds of groundwater sampling at the three new deep and the existing eight deep monitoring wells, with validation of all sampling results. The 2001 and 2002 investigations, thus, provide more complete field information to assess the conceptual model of fate and transport described in the RI report.

The findings concerning the groundwater flow direction and hydraulic gradient in the deep aquifer (groundwater flow southwesterly at a low gradient) determined from June 2001 groundwater elevation measurements are consistent with the 1993 RI report. The groundwater elevation measurements in March 2001 suggest a more southeasterly groundwater flow direction in some portions of the Site. The August 2002 elevation measurements are inconclusive. Based on historical measurements and the June 2001 measurements, it is concluded that a generally southwesterly groundwater flow direction exists in the deep aquifer.

The results of the analyses of groundwater show elevated levels of some of the radionuclides at wells LMW-06 and B29W10D, which are located near the former injection wells and at one more distant well, LMW-05 (Ra-226+Ra-228 standard exceeded by less than 9%), in March 2001, no elevated radionuclides in samples from the wells in June 2001, and elevated levels of uranium in one well in the vicinity of the former injection wells in August 2002. The elevated levels of radionuclides detected in March 2001 at

these three locations are attributed to the drilling method used to install the wells and the proximity of well B29W10D to new well LMW-06. It is concluded that the June 2001 and August 2002 samples are more representative of actual site conditions and elevated levels of radionuclides are not expected in the deep aquifer at Linde except in the area immediately adjacent to the former injection wells. These findings are consistent with the description of the fate and transport of the radionuclides injected into the deep aquifer as described in the RI report.

As detailed in Section 1 of Appendix B, the PHREEQC geochemical model was used to further predict the potential fate of the uranium discharged to the contact zone aquifer at Linde in the 1940s. Site characterization data from the 1993 RI report and findings of the 2001 groundwater investigation were used in the modeling. The results of the modeling indicate that the soluble uranium present in the waste could precipitate under the natural conditions in the contact zone aquifer. The modeling predicts that uranium solubility under site conditions is approximately 0.04 mg/L or approximately 27 pCi/L. The evaluation further notes that groundwater monitoring shows high concentrations of uranium in monitoring well sediments and low concentrations of uranium in the groundwater, supporting the premise that uranium is remaining in the solid phase in Linde groundwater.

As further detailed in Section 2 of Appendix B, estimates of the potential transport of uranium in the contact zone aquifer were made using a one-dimensional transport equation. Estimates assumed two cases, a single pulse source of uranium and a solubility-limited source. Based on these estimates, the assessment indicates that uranium should have been observed in monitoring wells during the 55 years since the injection occurred. Because the uranium has not been observed at the levels predicted, it is concluded that the premise is supported that the uranium has low solubility in the contact zone aquifer at Linde. This is consistent with the findings of the 1993 RI report.

Significantly, the geochemical model indicates that uranium concentrations under Site conditions would be expected to be approximately 27 pCi/L, which is less than the 40 CFR Part 192 standard. If uranium was present at concentrations approaching the modeling uranium solubility in groundwater, it would have been detected in the existing well network during the three sampling rounds.

#### **4.5.2 Shallow Groundwater**

As summarized above, the RI report describes the fate and transport of radionuclides in shallow groundwater in terms of potential horizontal flow with discharge to surface water, with a relatively impermeable layer precluding flow and contaminant transport vertically. No monitoring wells were installed in the shallow aquifer as part of the RI. Therefore, no field evidence of actual groundwater quality in the shallow aquifer was available at the time the RI report was prepared.

The 2001 investigation at Linde included the installation of three shallow monitoring wells and two rounds of sampling. Water quality data is not available for one of the wells (LMW-02), due to the low recharge rate for this well. The results from one of the shallow wells, LMW-03 showed the U-234+U-238, 40 CFR Part 192 standard of 30 pCi/L exceeded in unfiltered and filtered samples (<15% and 2% above the standard, respectively) collected in March 2001, not exceeded in the June 2001 samples, and exceeded (<4% above the standard) in the unfiltered sample from LMW-03 in August 2002.

Soil samples collected at Linde were subjected to leaching tests. The California WET and modified California WET were used. The results show that under the aggressive test conditions employed in the WET, radionuclides, especially uranium, may be leached from the soil. These conditions are considered to be more conservative than actual conditions at the site. It is noted that actual shallow groundwater concentrations of uranium are at levels above (<2% to 15% above the standard) or below the 40 CFR Part 192, Subpart A standards.

The March 2001 groundwater samples from the shallow wells were taken prior to remediation of the areas surrounding LMW-01 and LMW-03. The March 2001 soils samples had significantly elevated uranium concentrations. The CAL WET leaching analysis showed a high potential for leaching to groundwater, yet this was not supported by elevated readings in the groundwater at well LMW-03.

Results of sampling and analyses of shallow groundwater for the presence of metals and general chemistry parameters shows the presence of elevated levels of sodium, chloride and TDS in shallow groundwater from LMW-01 and elevated levels of sulfate and TDS in shallow groundwater from LMW-03.

The levels of chlorides, sodium and TDS in LMW-01 are among the highest reported in any of the data for Linde groundwater. The source of the elevated sodium and chloride and resultant elevated TDS at this location is not fully known. It may be partially explained if it assumed that effluent being injected into the deep aquifer years ago was allowed to overflow in the shallow system and migrate to this location. However, since elevated levels of sulfate and radionuclides were not detected at this location, it is not concluded that elevated sodium and chloride at this location resulted from effluent injection overflow. More likely explanations are that the use of salt for deicing may be impacting groundwater at this location or that fill material used at the site, said to be more than 17 feet at some locations, results in local impacts to groundwater, exacerbated by the on-going soil removal actions at Linde.

## **5. REMEDIAL ACTION OBJECTIVES AND APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARs) FOR LINDE GROUNDWATER**

### **5.1 Introduction and Remedial Action Objectives**

The current evaluation of Linde groundwater is being undertaken in accordance with CERCLA and the NCP. In assessing the need for groundwater remediation and options for groundwater remediation, if necessary, USACE first addressed the two threshold criteria that must be met for all remedial actions under CERCLA and the NCP. These threshold criteria are:

- the remedy must be protective of public health and the environment, and
- the remedy must attain ARARs.

USACE has adopted these threshold criteria as the general remedial action objectives for Linde groundwater. How USACE considered these general remedial action objectives in adopting specific criteria for Linde groundwater is addressed in the following sections.

### **5.2 Health Based Cleanup Criteria**

Under the NCP, which establishes USEPA regulations for compliance with CERCLA, acceptable exposure levels for known or suspected carcinogens are expressed in terms of lifetime cancer risk to an individual.

Under Section 300.400(e)(2)(i)(A)(2) of the NCP, “acceptable exposure levels are generally concentration levels that represent an excess upper bound lifetime cancer risk to an individual of between  $10^{-4}$  and  $10^{-6}$  using information on the relationship between dose and response.” The  $10^{-6}$  risk level shall be used as the point of departure for determining remediation goals for alternatives when ARARs are not available or not sufficiently protective because of the presence of multiple pathways of exposure.

As described below, ARARs are available in addressing groundwater at Linde and the ARARs available are considered to be protective.

### **5.3 ARAR Based Cleanup Standards**

Agencies responsible for remedial action under CERCLA must ensure that selected remedies meet ARARs. The following sections define ARARs and describe ARARs adopted by USACE for Linde.

#### **5.3.1 ARARs – Definitions**

Applicable requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance at a CERCLA site. An applicable requirement directly and fully addresses an element of the remedial action.

Relevant and appropriate requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria or limitations promulgated under federal or state environmental or facility siting laws that, while not “applicable” to a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is suited to the particular site. Only those state laws or regulations that are promulgated, are identified by the state in a timely manner, and are more stringent than federal requirements may be applicable or relevant and appropriate.

The ARARs for Linde Site groundwater are described below.

#### **5.3.2 USEPA Regulations for Protection of Groundwater at Uranium Mill Tailings Sites, 40 CFR Part 192, Subpart A**

The standards for groundwater protection found in 40 CFR Part 192, Subpart A, are not considered applicable to Linde Site groundwater because this regulation is only applicable to specific sites designated under the UMTRCA. However, USACE has determined that the groundwater standards in Subpart A of 40 CFR Part 192 are relevant and appropriate to groundwater at the Linde Site. This determination was made based on the similarity of ore processing activities to extract uranium and resulting radionuclides found in the waste after processing at Linde to the activities and wastes found at uranium mill sites where the regulation is applicable. As described in Section 4.3.3, the results of groundwater sampling at Linde in 2001 and 2002 were compared to the 40 CFR Part 192, Subpart A groundwater standard and analytes exceeding the 40 CFR Part 192 groundwater standards are considered to be COPCs in Linde groundwater. The 40 CFR Part 192 standards for the Linde groundwater COPCs are shown in Table 1.

As shown in Table 1 of this report, the maximum concentrations for radionuclides are: combined Ra-226 and Ra-228, 5 pCi/L; combined uranium-234 and uranium-238, 30 pCi/L; gross alpha particle activity (excluding radon and uranium), 15 pCi/L. As noted in Table 1, the 40 CFR Part 192, Subpart A standard for U-234 + U-238 of 30 pCi/L is considered to be satisfied when, under conditions of secular equilibrium, total uranium is 0.044 mg/L (44 µg/L) or less on a mass basis.

The point of compliance for groundwater concentrations listed in Subpart A is defined as the intersection of a vertical plane with the uppermost aquifer underlying the Site, located at the hydraulically downgradient limit of the disposal area plus that taken up by any liner, dike, or other barrier designed to contain the residual radioactive material (40 CFR Part 192.02). Since most of the Linde property has

been used for MED/AEC material processing or the subsequent storage of processing waste, the point of compliance is considered to be the Linde property line. Because liquid waste was injected into the deep groundwater at Linde, both the shallow and deep groundwater at the property line are considered points of compliance.

### 5.3.3 Evaluation of Other Potential ARARs

USACE evaluated the potential use of the USEPA's drinking water standards, 40 CFR Part 141, as ARARs in considering Linde groundwater. 40 CFR Part 141, also referred to as the National Primary Drinking Water Regulations, establishes standards of quality for drinking water supplied to users of public water systems. These standards, referred to as Maximum Contaminant Levels (MCLs), have been set for inorganic and organic constituents and radionuclides. The MCLs for radionuclides are the same as the 40 CFR Part 192 groundwater standards except that the MCL for total uranium is 30 µg/L, effective in December 2003. (As indicated in Table 12 of Appendix A, the results of samples from deep wells at Linde show that total uranium levels did not exceed 30 µg/L in wells other than the wells showing an exceedance of the 40 CFR Part 192 standard of 44 µg/L. As indicated in Table 16 of Appendix A, the samples from shallow well LMW-03 show total uranium exceeding 30 µg/L, but not exceeding the 44 µg/L 40 CFR Part 192 total uranium standard. As described below, the 30 µg/L standard is not, however, considered to be an ARAR for Linde groundwater.)

The MCLs of 40 CFR Part 141 are not considered applicable to Linde groundwater because these standards only apply to owners and operators of public water systems. In considering whether the MCLs should be considered as potential relevant and appropriate requirements, USACE reviewed groundwater quality conditions reported for the Linde Site area. As described in Section 2.1.3.1 of Appendix A, in the vicinity of the Linde Site, deep groundwater has high levels of dissolved solids, calcium, magnesium, sulfate, and chloride, with total dissolved solids ranging from 2,000 to 6,000 milligrams per liter (mg/L), sulfate content in the range of 1,000 to 1,500 mg/L and chloride from 1,500 to 2,000 mg/L. These high levels of total dissolved solids and salinity preclude the use of the water for potable consumption without costly treatment.<sup>6</sup>

Treatment processes such as reverse osmosis are available for treating water such as the water from the deep aquifer at Linde. A recent report by the U.S. Bureau of Reclamation (USBR) and Sandia National Laboratories (SNL) indicates, however, that treatment costs (not including the other costs associated with public water systems such as the distribution system, source development pumping, etc.) would be in the range of \$1 to \$3 per thousand gallons, which is 5 to 6 times the conventional treatment costs for fresh water (USBR/SNL 2003). The Town of Tonawanda is served by the Town municipal water system and the source, the Niagara River, provides more than an ample supply currently and into the future. Given the high cost of treatment and the availability of an ample source of municipal water, it is concluded that development of the deep groundwater at Linde to serve as a source of drinking water is not feasible. The shallow groundwater at Linde is not suitable as dependable water supply because the shallow subsurface formation has relatively low hydraulic conductivity with only limited lenses of permeable material, resulting in limited potential yields, as indicated by slow recharge rates, especially in the vicinity of LMW-02. Thus, neither the deep groundwater nor the shallow groundwater at Linde are considered to be sources of drinking water and the MCLs established under 40 CFR Part 141 are not considered to be relevant and appropriate to USACE's consideration of Linde groundwater. As described in Section 6.2, USACE, however, has considered the necessity for land use controls to ensure that Linde groundwater is not used for drinking or other purposes.

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<sup>6</sup> Thus, the natural groundwater in the deep zone where the MED/AEC wastes were injected contains high levels of constituents that would preclude use, even if MED/AEC waste residuals were not present.

USACE also evaluated the potential use of the New York State groundwater standards of 6 NYCRR 703 as ARARs in considering Linde groundwater. USACE first reviewed the definitions of fresh and saline groundwaters found in 6 NYCRR 700 and noted that saline groundwater is groundwater with chloride concentrations more than 250 mg/L or TDS concentrations more than 1,000 mg/L. As described above, the deep groundwater at Linde has natural levels of chlorides and dissolved solids exceeding the thresholds defining saline groundwater, and thus, USACE concluded that the deep groundwater at Linde is considered saline groundwater. The regulations in 6 NYCRR 701 state that all groundwaters in the state are assigned classifications of GA (fresh groundwater) or GSA (saline groundwater). USACE concluded that the deep groundwater at Linde is classified as GSA groundwater since it meets the definition of saline groundwater as described above.<sup>7</sup> USACE then reviewed the standards given in 6 NYCRR 703 and found that there are no specific numerical standards for groundwaters classified as GSA and therefore, concluded that the State groundwater standards do not provide contaminant-specific ARARs for the deep groundwater at Linde. In considering the shallow groundwater at Linde, USACE did not find regional groundwater quality information similar to the information available for deep groundwater and, therefore, no determination was made as to the classification of the shallow groundwater as Class GSA. A review of the Class GA standards indicates that the GA standards are set at or below the USEPA MCLs, with a number of the GA standards set at 50 percent of the MCLs. These standards also include federal secondary maximum contaminant levels which are set for aesthetic reasons. As in the case of USEPA MCLs, USACE has concluded that the 6 NYCRR 703 standards are not ARARs for deep and shallow Linde groundwater because these standards are set at drinking water levels or below and it is not feasible to develop Linde groundwater for drinking because of the poor water quality in the deep aquifer, high potential treatment costs and the availability of a dependable source of water service from the Town of Tonawanda, and lack of sufficient yield in shallow groundwater. As described above, the need for land use controls to ensure Linde groundwater is not used is addressed in Section 6.2.

## **6. DEVELOPMENT OF REMEDIAL ACTION ALTERNATIVES**

### **6.1 Assessment of the Need for and Feasibility of Linde Groundwater Remedial Actions**

#### **6.1.1 MED/AEC-Related Contaminants**

As described in the ROD for the Linde Site (USACE 2000) any remedial action conducted at Linde will not address any releases of hazardous substances that may have occurred due to operations conducted at Linde prior to or after MED/AEC operations, except to the extent that substances are commingled with MED/AEC era contamination. The MED/AEC-related radionuclides identified at the Site in soils include Ra-226, Th-230 and uranium. These radionuclides are also identified as constituents in the waste injected into the deep aquifer at Linde.

As described in Section 4, the COPCs for Linde groundwater are: radium, uranium, molybdenum, chromium, and mercury. Gross alpha is also considered to be a COPC.

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<sup>7</sup> 6 NYCRR 701 also identifies another classification for groundwater referred to as Class GSB. These groundwaters are saline groundwaters, having a chloride concentration in excess of 1,000 mg/L or a TDS concentration in excess of 2,000 mg/L. As described above, the natural concentrations of chlorides and TDS in deep groundwater in the Linde area exceed the thresholds that define groundwaters that would be classified as GSB. The regulations further state, however, that the GSB class shall not be assigned to any groundwaters of the State, unless the commissioner (of the NYSDEC) finds that adjacent and tributary groundwaters and the best usages thereof will not be impaired by such classification. Initial discussions with NYSDEC indicate that no such classifications of groundwaters to the GSB class have been implemented in New York State and that it is unlikely that such reclassification would be approved.

As also described in Section 4, The results from the August 2002 sampling of the deep wells show the 40 CFR Part 192 groundwater standards exceeded for uranium in the samples from well LMW-06 and the standard for molybdenum in the samples from wells B29W09D and LMW-06. Well B29W09D is located near the former injection wells in the vicinity of former Buildings 30 and 38. Well LMW-06 is located in the vicinity of the former injection wells near Building 8. Thus, the results of deep groundwater sampling in August 2002 show the 40 CFR 192 standards exceeded only in samples collected from wells in the vicinity of the former injection wells. The August 2002 deep groundwater results are generally consistent with the March 2001 results in terms of the wells showing exceedances of the groundwater standards, although the levels of uranium detected in the samples from LMW-06 (and B29W10D, which is located adjacent to LMW-06) were substantially higher in March 2001. The exception to this is an exceedance (<9% above the standard) of the Ra-226 + Ra-228 standard in the sample from LMW-05 in March 2001. The June 2001 sample results show no exceedances of the uranium standards. Exceedances of the gross alpha standard were detected in the samples from B29W05D in June 2001. Samples from these wells in March 2001 and August 2002 did not show the gross alpha standards exceeded.

The results of the sampling of shallow groundwater show two exceedances of the 40 CFR Part 192, Subpart A, standard for gross alpha in well LMW-01 and an exceedance (<4% above the standard) of the uranium standard in well LMW-03. There were no exceedances in samples from wells at or near the site boundary.

#### **6.1.2 Need for Linde Groundwater Remediation**

As described above, the results of sampling of deep groundwater at Linde show exceedances of the 40 CFR Part 192 numeric standards. Similarly, in shallow groundwater, the numeric standards of 40 CFR Part 192, Subpart A are met, except in the case of two exceedances of the gross alpha standard in one well and an exceedance (<4% above the standard) of the uranium standard in the other. While COPCs have been identified for Linde groundwater, there is no evidence that the 40 CFR Part 192 groundwater standards are exceeded in deep or shallow groundwater at the point of compliance, the property line.

In deep groundwater where injection of MED/AEC wastes occurred more than 50 years ago, groundwater monitoring indicates that elevated concentrations of MED/AEC-related constituents are found only in the immediate proximity of the injection wells. Geochemical modeling indicates that the constituent of principal concern injected in the 1940's, uranium, would be expected to have a concentration of less than the 40 CFR Part 192 standard once equilibrium conditions are reached. Based on these findings, the need for remediation of deep groundwater at Linde is not demonstrated and the ARARs are met.

Aggressive leaching tests of site soils show potential for radionuclide leaching, but results of sampling of shallow groundwater at Linde show only limited instances where 40 CFR Part 192 groundwater standards are exceeded (gross alpha at one location in March and June 2001 and uranium at another location in March 2001 and August 2002) and no evidence of the standards being exceeded at the property line. Given the extensive excavation and removal from the Site of soil containing elevated levels of uranium and other radionuclides, potential sources of leaching of radionuclides to shallow groundwater are now greatly reduced and exceedances of the 40 CFR Part 192, Subpart A groundwater standards are not expected. The shallow groundwater at the Site has been shown not to be an underground source of drinking water since it does not provide a sufficient quantity of water to supply a public water system. The need for remediation of shallow groundwater at the Linde Site is not demonstrated, and shallow groundwater is not considered further in this report.



### **6.1.3 General Response Actions and the Feasibility of Active Groundwater Remediation at Linde**

#### **6.1.3.1 General Response Actions**

In developing remedial action alternatives for Linde groundwater, USACE considered three categories of general response actions:

- No Action. CERCLA guidance requires that a no action response be considered to serve as a baseline for comparison to other potential responses or remedial alternatives.
- Limited Action. This response action is limited in scope and involves action such as monitoring and establishing and maintaining land use controls to limit or eliminate the potential for exposure to contaminants that may be present at a site.
- Active Remediation. Active remediation response actions include measures to contain, treat or remove site contaminants to limit or eliminate potential for exposure.

USACE considered no action and limited action response actions to be appropriate for evaluation as remedial action alternatives for Linde groundwater. These alternatives are further described in Section 6.2. The feasibility of active remediation of Linde groundwater is assessed in Sections 6.1.3.2 and 6.1.3.3, below.

#### **6.1.3.2 Feasibility of Active Remediation of Deep Groundwater at Linde**

As described in the foregoing sections of this report, approximately 55 million gallons of liquid wastes containing MED/AEC constituents were injected into the subsurface at Linde in the 1940's. As further detailed in Sections 3.1.1 and 5.2 of Appendix A, the waste was injected under pressure and would have migrated into bedrock fractures and into the more permeable zones overlying the bedrock. The extent of the migration of the liquid injected under pressure is unknown, but the geochemical modeling (Appendix B) of the uranium present in the liquid indicates that under the conditions present, the solubility of the uranium is estimated to be about 27 pCi/L. It was concluded, therefore, that the bulk of uranium present in the wastes would have precipitated after discharge and would not be extensively present in the dissolved phase in groundwater. Further modeling (Appendix B) indicated that uranium could have migrated following the injection and, if so, would be present in groundwater downgradient of the injection wells. Groundwater monitoring, however, indicates that evidence of elevated levels of MED/AEC-related constituents in groundwater at Linde is limited to locations near the injection wells. Given these findings, USACE considered the following options for active remediation of Linde groundwater.

#### **Groundwater Containment**

Implementation of containment at the Linde site would involve the isolation of the groundwater showing MED/AEC radionuclides at levels exceeding the 40 CFR Part 192 groundwater standards.

Technologies available for containment include barrier walls such as slurry walls constructed of highly impermeable materials (bentonite mixtures etc.), typically constructed in the overburden, or grout curtains constructed in the bedrock. Slurry walls may be effective in containment of contaminated groundwater where they are keyed into highly impermeable subsurface formations. At the Linde Site, the bedrock is fractured and may contain solution cavities, likely requiring bedrock grouting in association with a slurry wall. Given the uncertainties associated with grouting the bedrock, needs to extend any slurry wall down

to depths exceeding 100 feet to ensure effectiveness, uncertainty as to where a slurry wall would be placed to ensure containment and conflicts with the numerous utilities present on the Site, the use of barrier walls for containment of contaminated groundwater on the Linde Site was eliminated from consideration.

Depending on site conditions, containment of contaminated groundwater may also be accomplished hydraulically. A properly installed groundwater extraction well lowers groundwater elevations in the well vicinity, creating a cone of depression in the groundwater table that induces groundwater flow toward the well. Depending on specific conditions, contaminated groundwater flow directions can be reversed and, thus, contaminated groundwater may be contained within a specified area. This technology is well known and is also used in combination with treatment in the removal of contaminants from extracted groundwater.

The potential effectiveness of hydraulic containment of groundwater is uncertain at Linde, however, because the subsurface areas showing MED/AEC constituents at levels exceeding the 40 CFR Part 192 groundwater standards includes fractured bedrock and potential solution cavities which may not be continuous. While pumping in relatively homogenous formations such as sand has been shown to be effective, the performance of pumping to hydraulically contain contaminated groundwater at Linde is not considered reliable due to the subsurface conditions. Similarly, the effectiveness of removing contaminated groundwater from the fractured bedrock using pumping is uncertain. Based on these considerations, containment whether by a subsurface barrier or hydraulically, by pumping, was eliminated from further consideration by USACE.

### **In-Situ Treatment of Groundwater**

In-situ treatment refers to remedial action technologies that reduce contaminant levels in the impacted media (in this case, groundwater) without physical removal of the impacted media. A number of such treatment technologies have been used to effectively treat contaminants such as volatile organic compounds in groundwater. There are some technologies potentially available for the treatment of metals such as uranium in groundwater, but few have been demonstrated to be technically sound and cost effective. One promising technology is the use of a permeable reactive barrier (PRB). PRBs are subsurface permeable walls installed across the flow path of contaminated groundwater. As the flow of groundwater passes through the media in the PRB, treatment is facilitated. In a demonstration project in Utah, uranium contaminated groundwater was effectively treated with several different materials (media within the PRB) including zero valent and ferrous iron (USEPA 2000). Due to the depth to which a PRB would have to be installed to intercept the deep groundwater and potentially high associated cost, difficulty in excavation into bedrock at depth and uncertainties of treatment given the physical and chemical characteristics of the deep groundwater at Linde, use of a PRB was eliminated from further consideration. While other technologies for in-situ treatment have been tested, none were identified as commercially available for application to deep groundwater at Linde.

### **Ex-Situ Treatment of Groundwater**

As briefly identified above, pumping and treating contaminated groundwater is widely used. Given the uncertainty of the effectiveness of capturing contaminated groundwater in the deep subsurface, the need for the use of treatment to address deep groundwater contamination at Linde is not demonstrated. There are treatment processes available, such as reverse osmosis, to treat water for uranium and these processes would also be effective in removal of the high dissolved solids and chlorides that are naturally present. Ex-situ treatment was eliminated, however, from further consideration given the uncertainty associated with capturing the MED/AEC-related constituents that were injected into deep groundwater and precipitated out in the subsurface at Linde.

### **Remediation of Source Material**

As described in Section 3.3, approximately 55 million gallons of liquid wastes from MED/AEC operations were discharged to the deep subsurface via injection wells at Linde from 1944 to 1946. As also described in Section 3.3 and detailed in Appendix A, Section 2.4.2, approximately 3 curies of natural uranium were discharged as part of the waste, equating to approximately 9,742 pounds or approximately 8.4 cubic ft of uranium, in solid form. As a means to facilitate the remediation of groundwater contamination in the deep subsurface at Linde, the isolation or the removal of the solid phase uranium present in the deep subsurface was assessed. As described in Section 4.5 and Appendix B, geochemical modeling indicates that the uranium in the liquid waste discharged to the subsurface would likely be present only at low concentrations (approximately 27 pCi/L) under equilibrium conditions with natural groundwater in the area. The bulk of the uranium discharged would be present in the solid phase in fractures or solution cavities in the bedrock or the overlying, more permeable formation. The extent of this solid phase, laterally or with depth is not known. Illustrative of the complexity of the subsurface is the discovery during the DOE RI (1990-1991) of a yellow precipitate in a boring in the rock at a depth of approximately 100 ft, near the location of a former injection well near Building 8. The yellow precipitation was noted in a thin fracture in the rock core and the RI report indicated an associated elevated gamma reading. USACE boring LMW-06 in 2001 was drilled at a location immediately adjacent to the 1990-1991 boring where the yellow precipitate was found. No yellow precipitate was found in the boring for LMW-06, despite its close proximity to the location where the yellow precipitate was seen.

To isolate or remove the solid phase uranium present in the subsurface, an approximate understanding of the areal and vertical extent of the uranium would be required. A systematic program of deep exploratory borings with observations and analyses of material from soil and rock core samples would be required. As evidenced in the experience at the location of LMW-06, a widespread continuous strata of solid phase uranium is not present. Thus, even a series of borings located at distances of 10 to 25 ft apart, to depths of 150 ft, would not guarantee finding the relatively small amount of uranium present. Even if a fairly accurate understanding of location of the uranium was determined, there are no known means to isolate such areas from the surrounding groundwater except grouting, which may not be effective given the nature (fracturing and solution cavities) of the formation.

For removal of the uranium (if found) from the subsurface, in-situ leaching or solution mining was considered. This involves injection of an agent (acid or base) into the subsurface to dissolve the uranium and pumping of the dissolved material to the surface for treatment. Given the uncertainties in the subsurface characteristics and the potential for exacerbating groundwater contamination, the use of in-situ leaching or solution mining is not considered feasible. The excavation of the uranium from the subsurface at depths of 100 ft deep would involve deep excavation, dewatering, rock drilling/blasting with potential jeopardy to on-site buildings and facilities and prohibitive costs.

Based on the considerations described above and the reality that even after remedial actions to remove source materials are completed, there would be no surety that all the source materials are removed, USACE has concluded that the remedial actions to remove source materials as a means to remediate groundwater are not feasible at Linde.

## 6.2 Remedial Action Alternatives for Linde Groundwater

The remedial action alternatives for Linde groundwater are limited because currently the remedial action objective of compliance with ARARs is met based on the August 2002 results. Because ARARs are met and the ARARs are considered protective, and since there is no current or reasonably expected exposure to groundwater, there is no subsequent risk. Thus, the CERCLA threshold criterion of protection of human health and the environment is currently met. However, while the use of on-site shallow or deep groundwater is not envisioned, the numeric thresholds of the 40 CFR Part 192 groundwater standards are exceeded at some locations on the property, within the property line and, there are no current controls in place to preclude the use of on-site groundwater. Accordingly, USACE considered two alternatives for Linde groundwater. The alternatives considered are:

- No Action. Consideration of a no action alternative is required under CERCLA. Under this alternative site groundwater would be left as is. No monitoring would be conducted.
- Limited Action. Under this alternative, periodic monitoring of site groundwater would be conducted. The analytes to be monitored would be limited to those related to the site and showing an exceedance of the 40 CFR Part 192 groundwater standards during the 2001 and 2002 groundwater sampling by USACE. A detailed monitoring plan would be developed, with concurrence from NYSDEC and USEPA, that would specify the wells to be monitored, the analytes, the sampling frequencies, and the conditions under which monitoring and specific land use controls could be terminated.<sup>8</sup> Land use controls would be established to preclude the use of site groundwater and would include prohibitions on drilling wells and/or use of any existing wells. A real estate plan for this alternative is included in Appendix C. At the end of five years, the site conditions would be reviewed to verify that land use controls are effective and ARARs continue to be met. The potential need for subsequent 5-year reviews would also be assessed. If monitoring is no longer required, the need for 5-year reviews could be eliminated.

## 7. ANALYSIS OF ALTERNATIVES

As described above, USACE has identified two alternatives for groundwater at the Linde Site. These are:

- No Action
- Limited Action

The alternatives for Linde groundwater described in Section 6 were evaluated using CERCLA criteria. These criteria are described in Section 7.1. The results of the detailed evaluation of the Linde groundwater alternatives are summarized in Section 7.2 through 7.6.

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<sup>8</sup> The monitoring plan for groundwater would consider statistically based procedures to assess the sampling results and conditions under which monitoring could be terminated. Such statically based procedures are available in USEPA documents such as RCRA Statistical Analysis of Groundwater Monitoring Data (USEPA 530/SW-89/026) and Methods for Evaluating the Attainment of Cleanup Standards, Volume 2: Ground Water (USEPA 230-R-92-014, July 1992).

## 7.1 Evaluation Criteria

As described in Section 5.1, the following two criteria are CERCLA threshold criteria and must be met.

- *Overall Protection of Human Health and the Environment* - addresses whether an alternative provides adequate protection and describes how risks are eliminated, reduced, or controlled through treatment, engineering controls, or institutional controls.
- *Compliance with Federal and State Environmental Regulations* - addresses if a remedy would meet all of the federal and state ARARs.

The following CERCLA criteria are considered balancing criteria and are used to weigh major tradeoffs among alternatives being evaluated.

- *Long-Term Effectiveness and Permanence* - addresses the remaining risk and the ability of an alternative to protect human health and the environment over time, once cleanup goals have been met.
- *Short-Term Effectiveness and Environmental Impacts* - addresses the impacts to the community and site workers during cleanup including the amount of time it takes to complete the action.
- *Reduction in Toxicity, Mobility, or Volume Through Treatment* - addresses the anticipated performance of treatment that permanently and significantly reduces toxicity, mobility, or volume of waste.
- *Implementability* - addresses the technical and administrative feasibility of an alternative, including the availability of materials and services required for cleanup.
- *Cost* - compares the differences in cost, including capital, operation, and maintenance costs.

The following are considered CERCLA modifying criteria and are generally taken into account after public comment is received on the PP.

- *State Acceptance* - evaluates whether the State agrees with, opposes, or has no comment on the preferred alternative.
- *Community Acceptance* - addresses the issues and concerns the public may have regarding each of the alternatives as expressed in comments.

These modifying criteria will be addressed following the opportunity for state and community comments on the Proposed Plan for the Groundwater OU. The results of the evaluation of the groundwater alternatives in terms of the CERCLA threshold and balancing criteria are addressed in the following sections.

## **7.2 Alternative 1 – No Action**

### **Overall Protection of Human Health and the Environment**

Alternative 1 is not considered to be protective of human health and the environment. While the ARARs, the 40 CFR Part 192 groundwater standards, are not exceeded at the point of compliance based on current (August 2002) sampling results, the numeric standards are exceeded at locations within the property (i.e., in the deep groundwater in the vicinity of the former injection wells). Under the no action alternative, there is no means to ensure that on-site groundwater is not inadvertently used and, therefore, there is no assurance that any potential adverse health effects associated with the use of the on-site water would not occur.

### **Compliance with ARARs**

Results of groundwater monitoring indicate that 40 CFR Part 192 groundwater standards are met at the point of compliance based on the August 2002 results. The numeric standards of 40 CFR Part 192 are exceeded, however, in deep groundwater on the property near the locations of the former injection wells.

### **Long-Term Effectiveness and Permanence**

This alternative is not effective and not permanent because there would be no means to ensure that on-site groundwater is not used and there is not means to monitor potential groundwater quality changes in the long term.

### **Short-Term Effectiveness and Environmental Impact**

This alternative is considered to be effective in the short term because ARARs are met and no remedial action would be taken that would result in short term environmental impacts.

### **Reduction in Toxicity, Mobility or Volume Through Treatment**

There is no reduction in toxicity, mobility or volume of contaminants associated with this alternative.

### **Implementability**

This alternative is easily implementable because no action would be taken.

### **Cost**

There are no costs associated with Alternative 1.

## **7.3 Alternative 2 – Limited Action**

### **Overall Protection of Human Health and the Environment**

This alternative is considered protective of human health and the environment because ARARs are met based on current (August 2002) sampling results. However, as described in the evaluation of Alternative 1, the numeric standards of 40 CFR Part 192 are exceeded at locations within the property boundary near the former injection wells. Differing from Alternative 1, however, Alternative 2 includes monitoring to verify that ARARs are met and ensure that any potential off-site migration of contaminated groundwater

is detected. Land use controls would be put in place to ensure that use of the groundwater is prohibited. There are no impacts to workers or community health.

### **Compliance with ARARs**

This alternative is compliant with ARARs because ARARs are currently met and monitoring would continue to verify that ARARs are met and that 40 CFR Part 192 groundwater standards are met at the point of compliance. As described above, the numeric standards of 40 CFR Part 192 are exceeded within the property boundary near the former injection wells.

### **Long-Term Effectiveness and Permanence**

This alternative is considered to be effective in the long term and permanent, based on current information. Land use controls would preclude the use of on-site groundwater and if it is determined through monitoring that ARARs are exceeded, further action may be taken. While it is not anticipated that further action would be required, such actions could include revisions to the ROD for groundwater and further consideration of active groundwater remedial measures.

### **Short-Term Effectiveness and Environmental Impact**

This alternative is effective in the short term because ARARs are met and no environmental impact is involved.

### **Reduction in Toxicity, Mobility or Volume Through Treatment**

There is no reduction in toxicity, mobility or volume of contaminants involved in this alternative.

### **Implementability**

This alternative is relatively easy to implement. Long term monitoring and the imposition of land use controls would be moderately complex.

### **Cost**

The cost of this alternative includes the costs for: development of a monitoring plan and land use control plan; easements; annual sampling of monitoring wells for a period of five (5) years; monitoring well replacement, if required; implementation of land use controls; and review of Site conditions at the end of five years. In estimating costs, it was conservatively assumed that costs associated with monitoring, land use controls and 5-year reviews would continue for an extended time. The actual period over which costs would be incurred may be much shorter, since the need for incurring these costs would depend upon the results of monitoring. In accordance with current guidance developed by USACE with USEPA (USACE/USEPA 2000), the present values of these estimated one-time, annual and periodic costs were calculated based on a discount rate of seven (7) percent (%). The present value cost of this alternative is estimated to be \$800,000.

## 8. COMPARISON OF ALTERNATIVES

The following sections summarize a comparative analysis of the Linde groundwater alternatives in terms of the CERCLA threshold and balancing evaluation criteria described in Section 7.1.

### 8.1 Overall Protection of Human Health and the Environment

Alternative 2 is considered to be protective because land use controls prohibiting the use of on-site groundwater would be implemented and monitoring would be provided to detect any changes in conditions that may have adverse effects. Alternative 1 is not considered to be protective.

### 8.2 Compliance with ARARs

Alternatives 1 and 2 are equal in terms of compliance with ARARs based on the August 2002 sampling results. Alternative 2, however, includes monitoring to verify compliance with ARARs and therefore, is ranked higher than Alternative 1 in terms of compliance with ARARs.

### 8.3 Long-Term Effectiveness and Permanence

Alternative 2 is ranked over alternative 1, because Alternative 1 is not effective and permanent because there would be no means to ensure that on-site groundwater is not used and there is no means to monitor potential changes in the quality of groundwater at the Site.

### 8.4 Short-Term Effectiveness and Environmental Impact

Alternatives 1 and 2 are ranked equal in terms of this criteria.

### 8.5 Reduction in Toxicity, Mobility or Volume Through Treatment

Alternatives 1 and 2 are ranked equal in terms of this criterion because neither of the alternatives reduce toxicity, mobility or volume of contaminants.

### 8.6 Implementability

Alternative 1 ranks over alternative 2 because of the added complexity of monitoring and land use controls associated with alternative 2.

### 8.7 Cost

The estimated present value for implementation of the alternatives considered for Linde groundwater are:

Alternative	Description	Estimated Present Value Cost (\$)
1	No Action	0
2	Limited Action	800,000

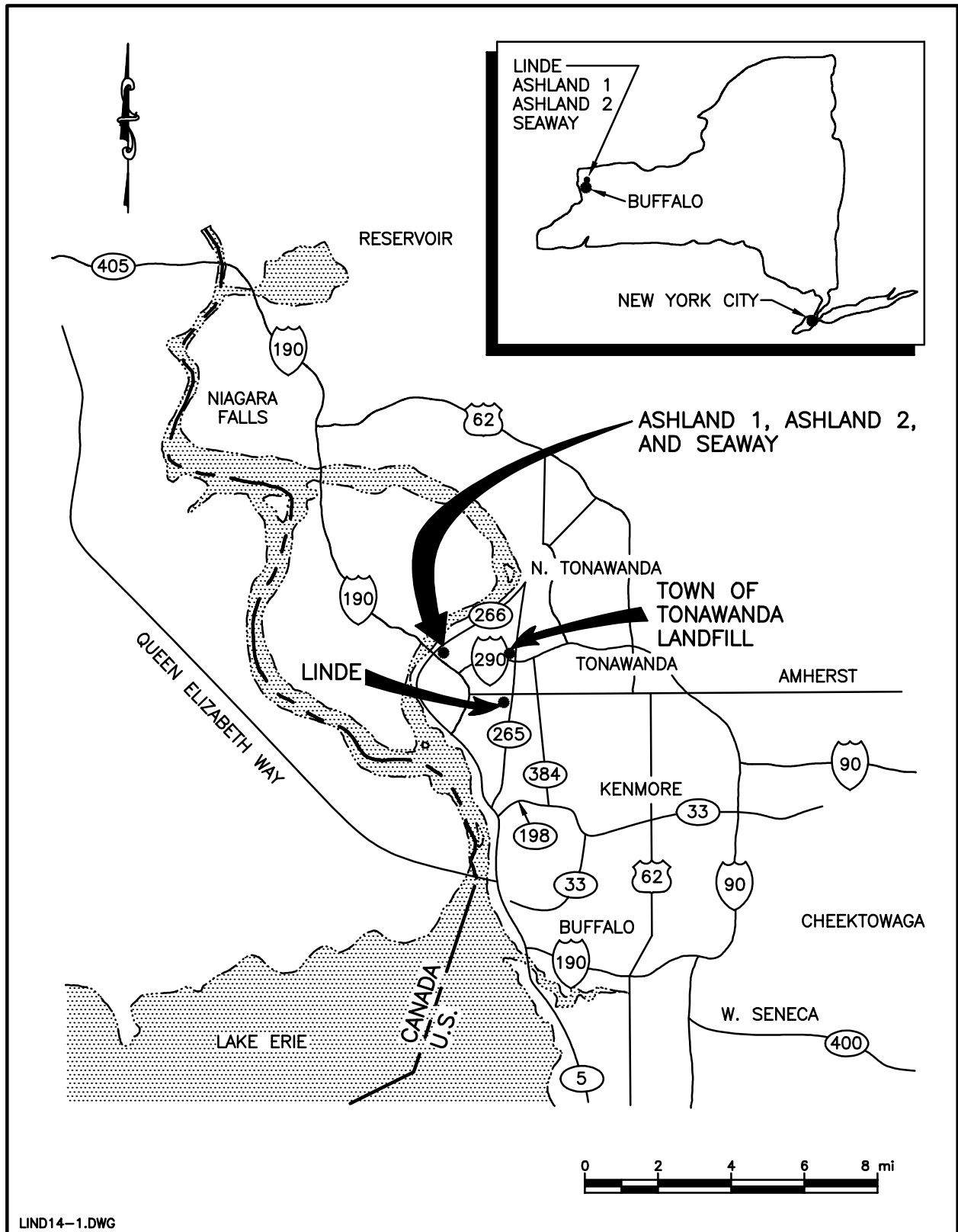
Table 4 compares the alternatives for Linde groundwater.



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## FIGURES



**FIGURE 1**  
**REGIONAL LOCATION OF THE TOWN OF TONAWANDA, NEW YORK AND THE**  
**ASHLAND 1, ASHLAND 2, SEAWAY, LINDE AND THE TOWN OF TONAWANDA LANDFILL SITES**

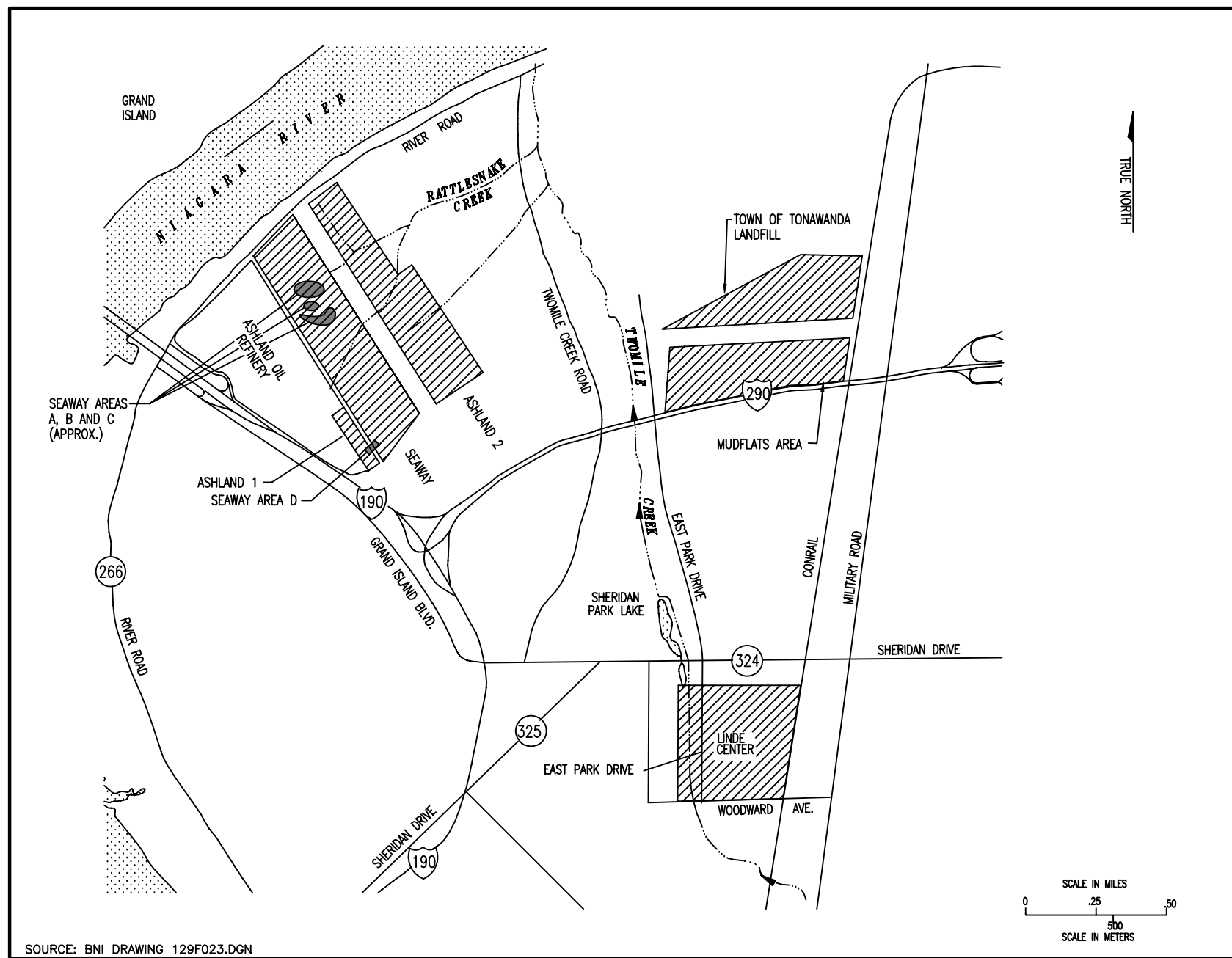
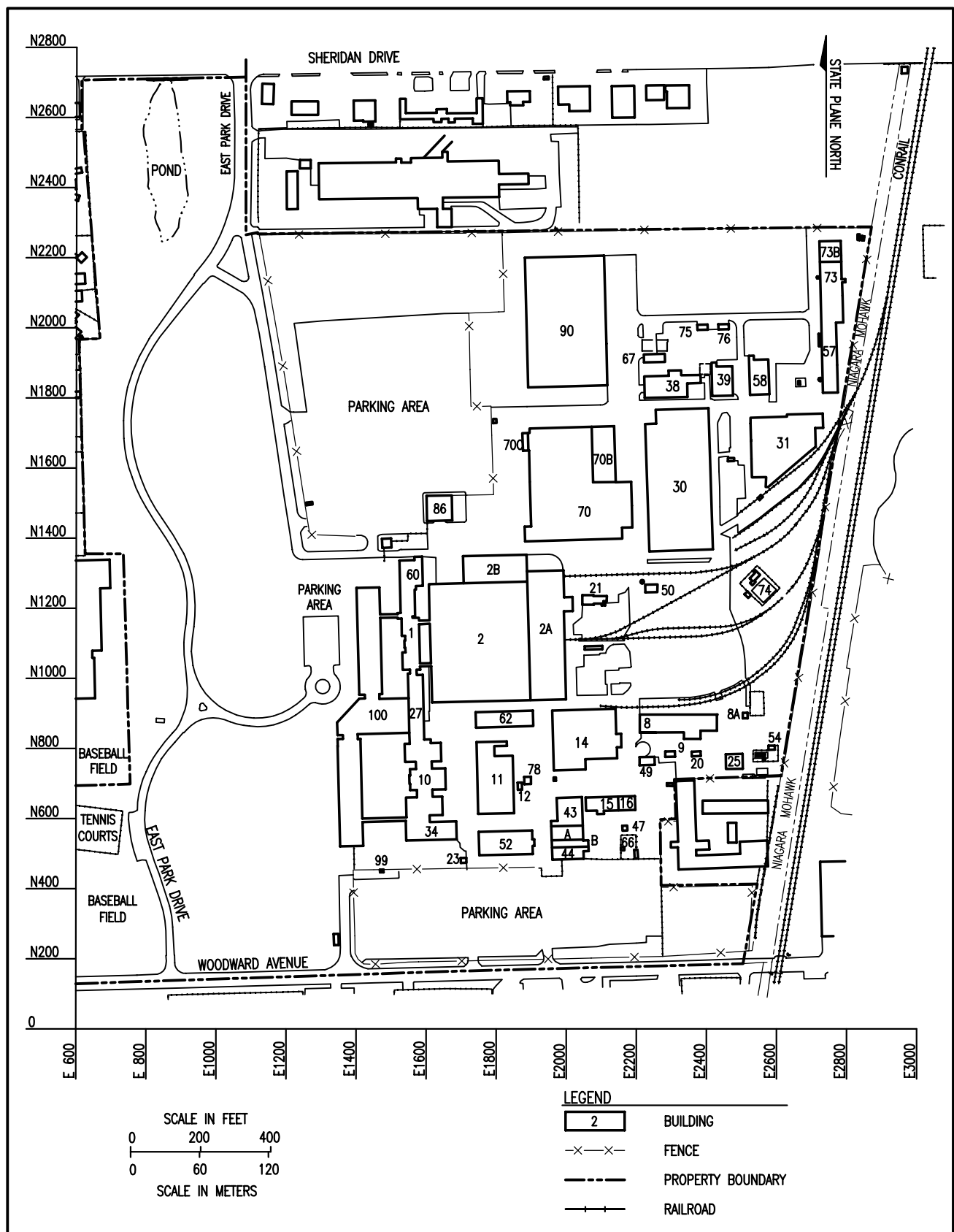
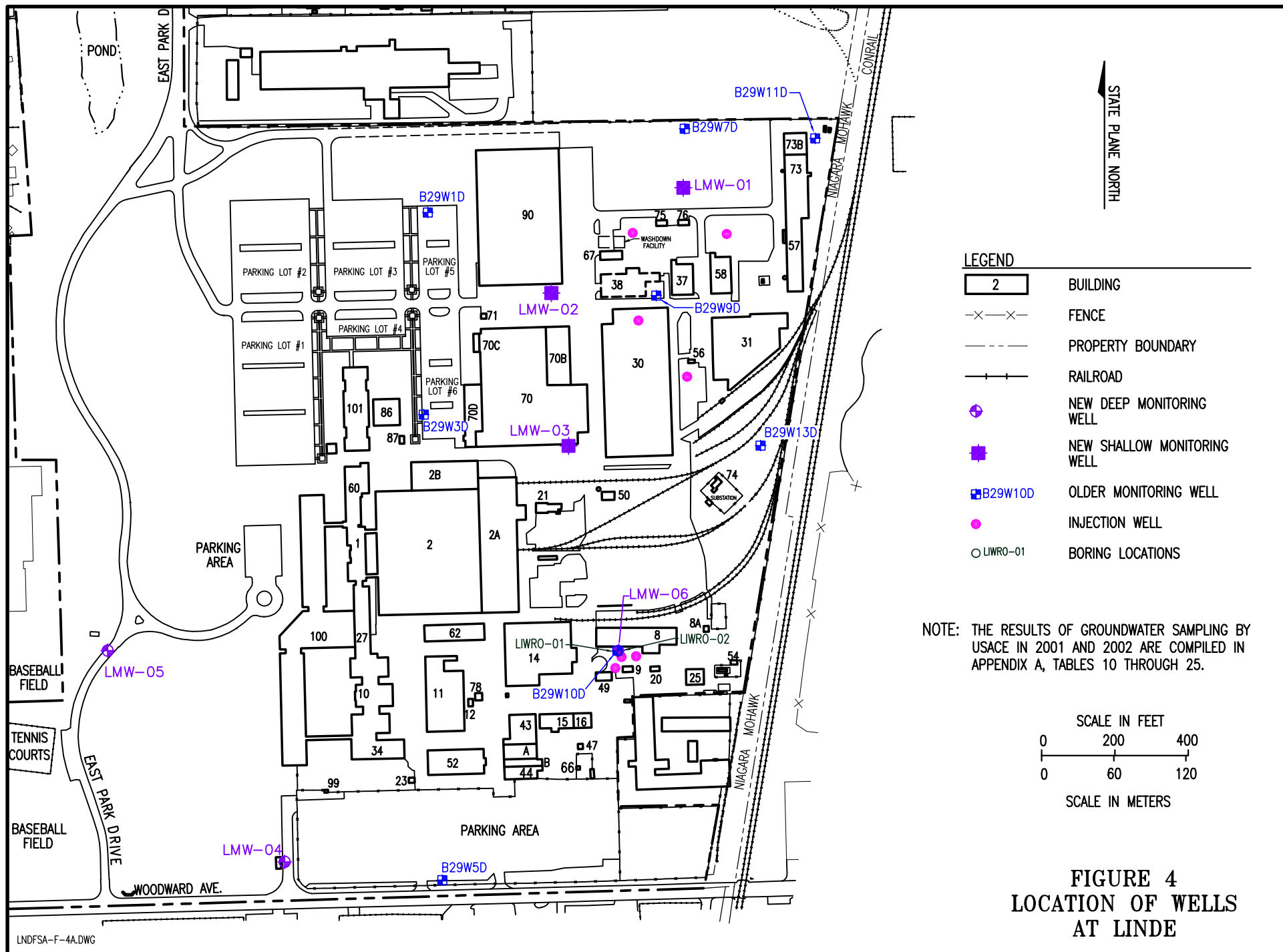


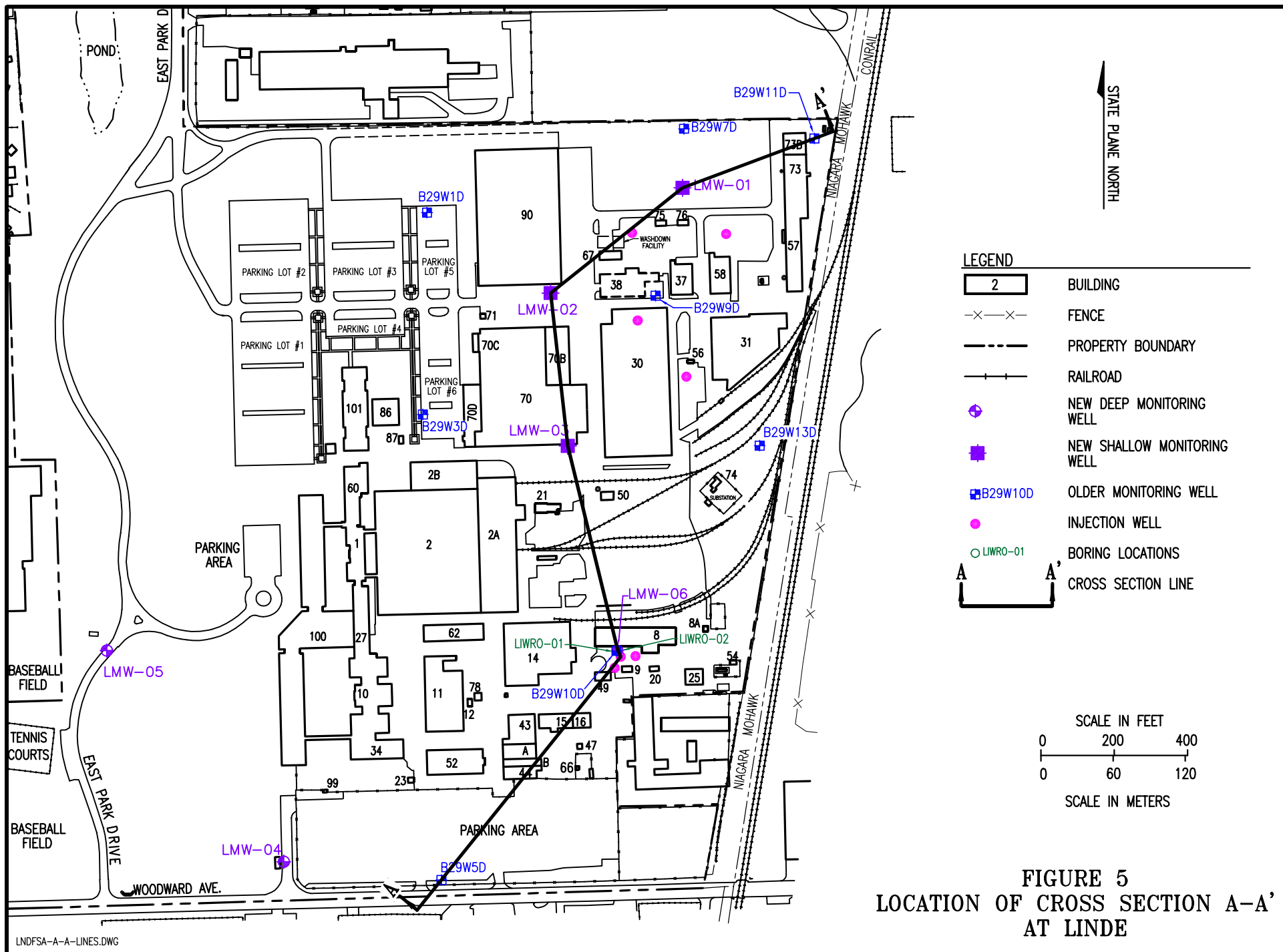
FIGURE 2  
LOCATIONS OF ASHLAND 1, ASHLAND 2,  
SEAWAY, LINDE AND THE TONAWANDA LANDFILL SITES

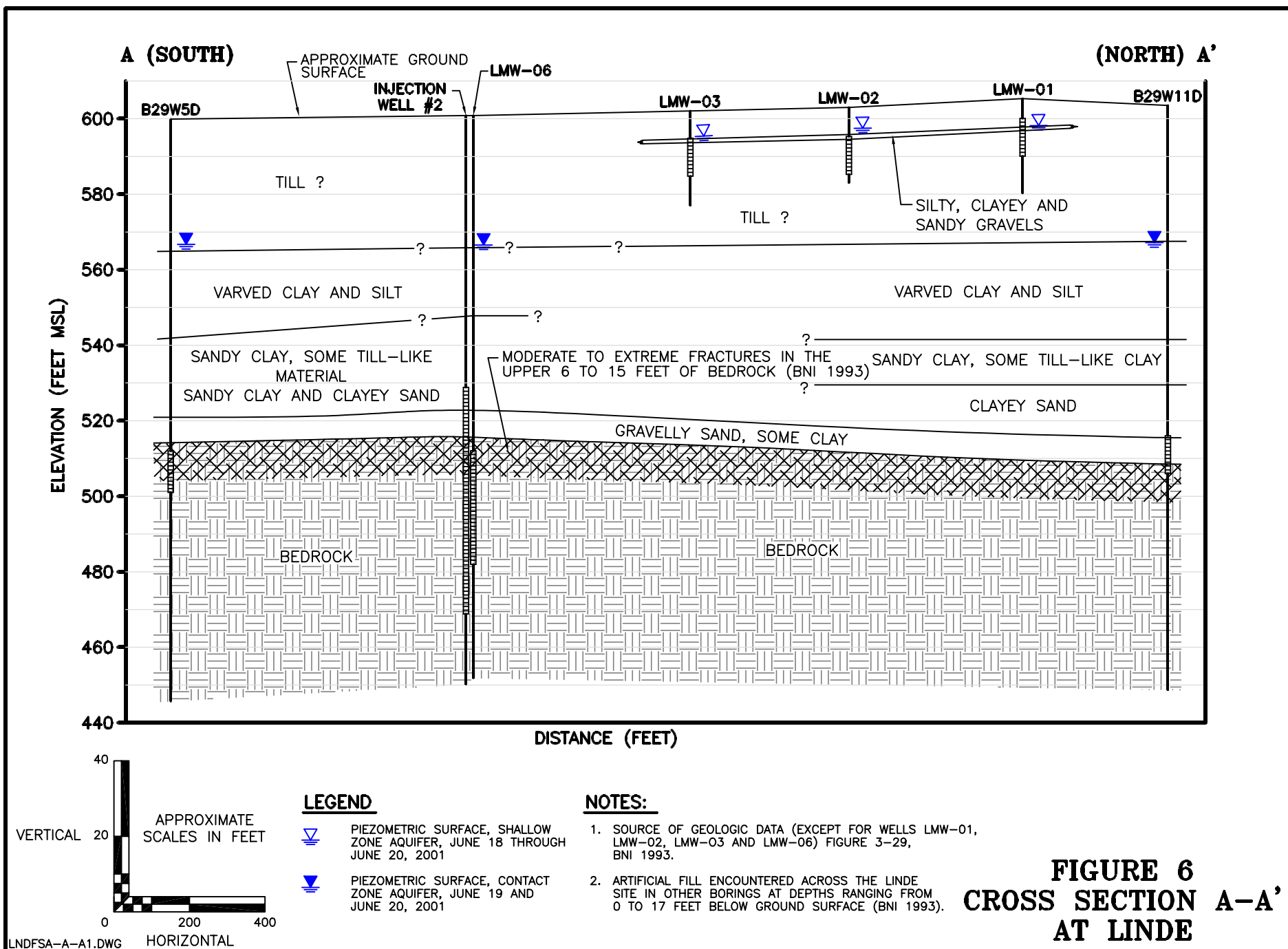


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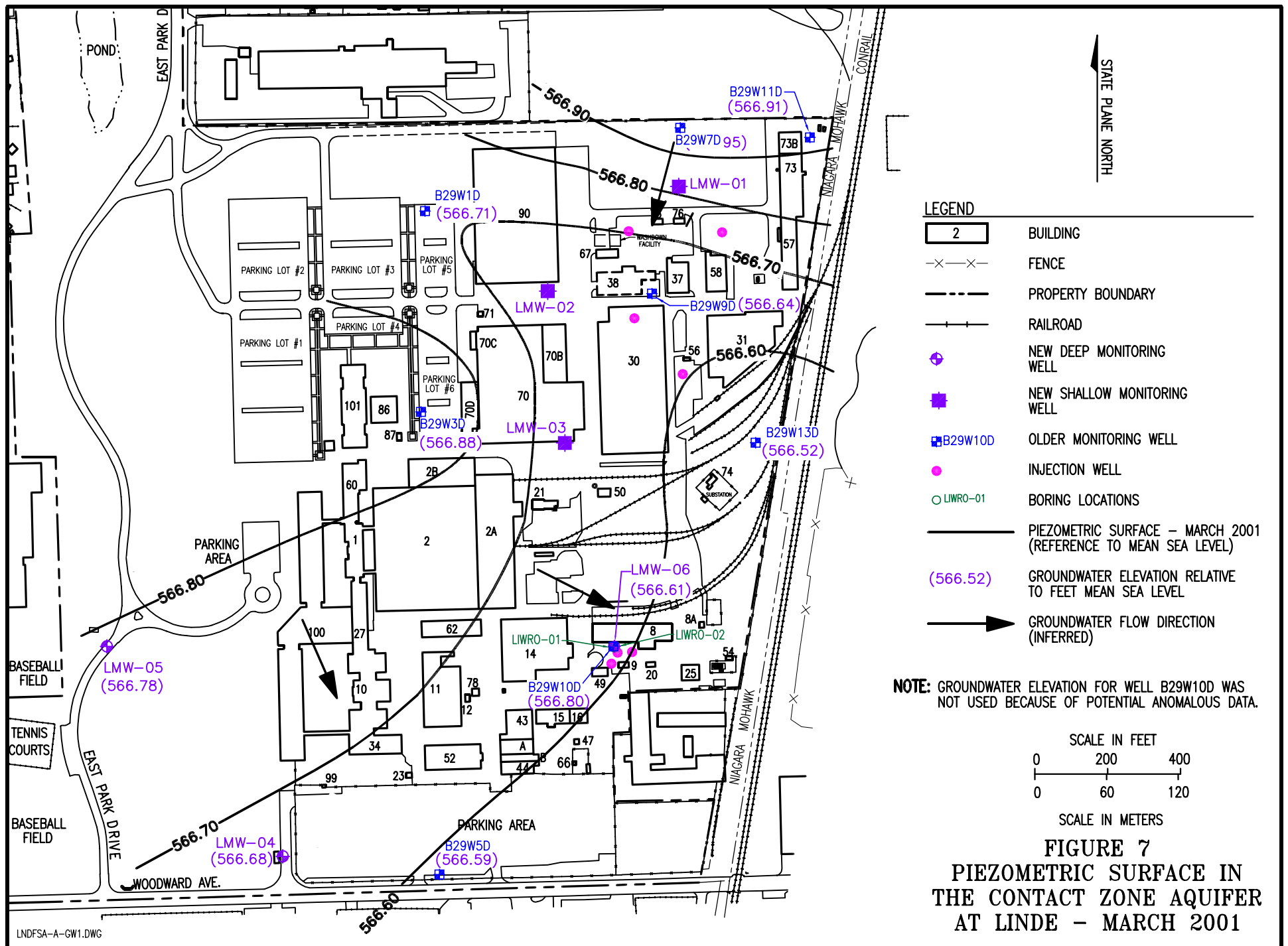
**FIGURE 3**  
**LINDE SITE LOCATIONS**

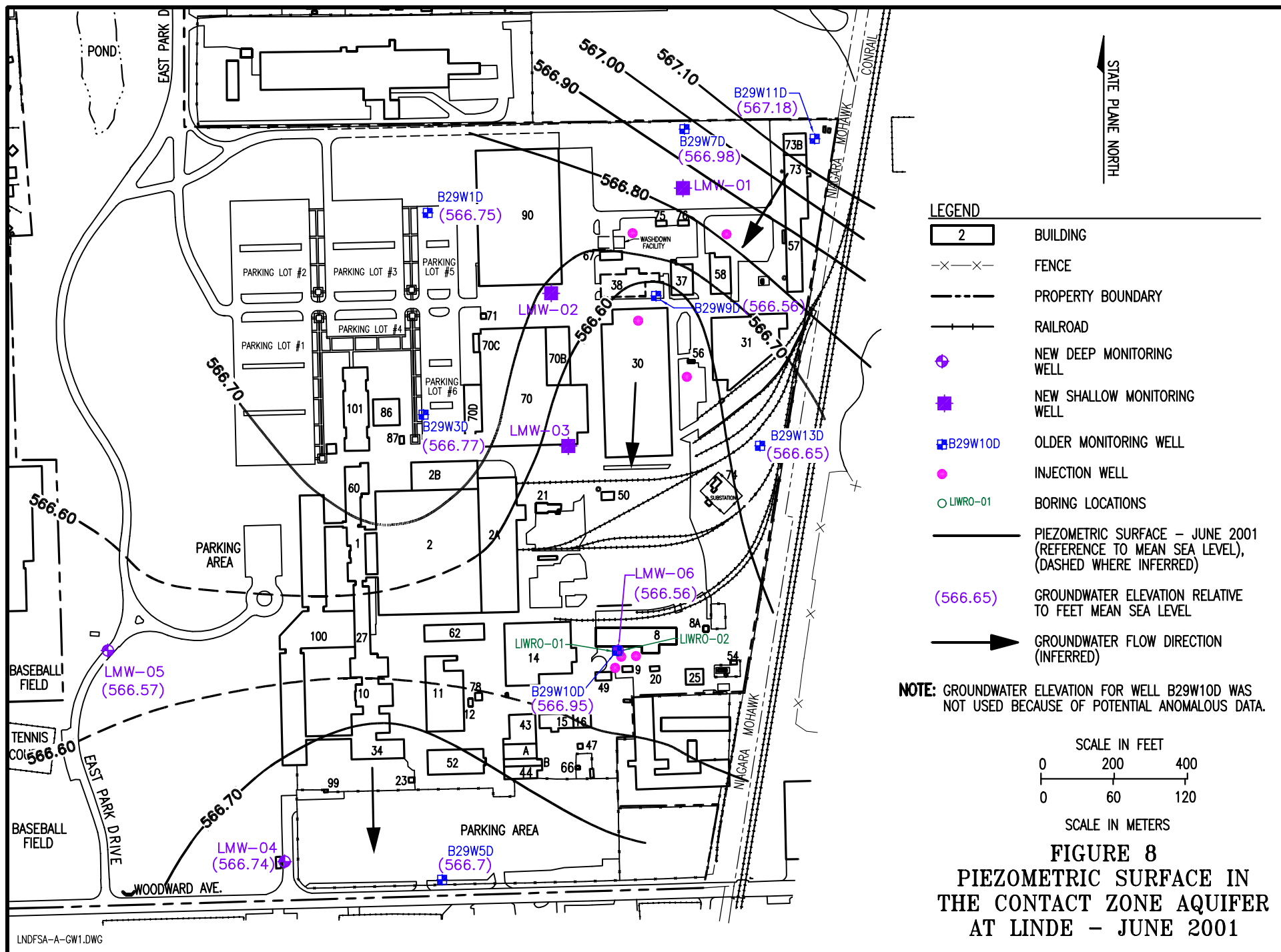












## **TABLES**

**Table 1**  
**40 CFR Part 192, Subpart A Groundwater Standards**  
**for Linde Groundwater Contaminants of Potential Concern (COPCs)**

<b>Constituent</b>	<b>Concentration <sup>(1)</sup></b>
Chromium	0.05
Mercury	0.002
Molybdenum	0.1
Combined Radium-226 and Radium-228	5 pCi/L
Combined Uranium-234 and Uranium-238 <sup>(2)</sup>	30 pCi/L
Gross Alpha-particle Activity (excluding radon and uranium)	15 pCi/L

**Notes:**

<sup>(1)</sup> Milligrams per liter, unless stated otherwise.

<sup>(2)</sup> Where secular equilibrium obtains, this criterion will be satisfied by a concentration of 0.044 milligrams per liter (0.044 mg/L). For conditions of other than secular equilibrium, a corresponding value may be derived and applied, based on the measured site-specific ratio of the two isotopes of uranium.

**Table 2 - Deep Wells**  
**March 2001, June 2001, and August 2002 Sample Results Exceeding**  
**40 CFR Part 192 Groundwater Standards (1)**

Analyte	Deep Wells - March 2001									Deep Wells - June 2001				Deep Wells - August 2002					
	Ra-226+Ra-228	U-234 + U-238	U-234 + U-238	Uranium (total)	Uranium (total)	Molybdenum	Molybdenum	Chromium	Mercury	Gross Alpha (2)	Gross Alpha (2)	Molybdenum	Molybdenum	U-234 + U-238	U-234 + U-238	Uranium (total)	Uranium (total)	Molybdenum	Molybdenum
40 CFR Part 192 Standard	5 pCi/L	30 pCi/L	30 pCi/L	44 µg/L	44 µg/L	0.1 mg/L	0.1 mg/L	0.05 mg/L	0.002 mg/L	15 pCi/L	15 pCi/L	0.1 mg/L	0.1 mg/L	30 pCi/L	30 pCi/L	44 µg/L	44 µg/L	0.1 mg/L	0.1 mg/L
Preparation	Unf.	Unf.	Fil.	Unf.	Fil.	Unf.	Fil.	Unf.	Unf.	Unf.	Fil.	Unf.	Fil.	Unf.	Fil.	Unf.	Fil.	Unf.	Fil.
Date	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Jun-01	Jun-01	Jun-01	Jun-01	Aug-02	Aug-02	Aug-02	Aug-02	Aug-02	Aug-02
Units	pCi/L	pCi/L	pCi/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	pCi/L	pCi/L	mg/L	mg/L	pCi/L	pCi/L	µg/L	µg/L	mg/L	mg/L
Well																			
B29W05D	1.3	0.89	0.44	1.43	0.52	ND	0.008	0.002	ND	9	27	ND	ND	0.58	0.4	0.106	0.166	ND	ND
B29W07D	1.3	0.18	0.12	0.21	0.09	0.048	0.053	0.002	ND	16	4	0.033	0.053	0.49	0.34	0.731	0.361	0.033	0.036
B29W09D	1.4	1.3	0.78	2.36	1.92	0.44	0.45	ND	ND	52	36	0.42	0.42	1.4	0.37	1.06	0.63	0.33	0.34
B29W10D	1.4	671	332	765	470	0.25	0.24	0.096	0.013	-16	-7	0.22	0.20	NS	NS	NS	NS	NS	NS
LMW-05	5.4	14.9	2.3	26.6	18.1	0.008	0.008	ND	ND	6	1	0.008	ND	5.75	4.32	9.04	7.79	ND	ND
LMW-06	70	544	339	837	390	0.37	0.37	0.004	0.0003	11	2	0.15	0.15	66.1	37.3	98.8	62.9	0.27	0.24

(1) Results exceeding the 40 CFR Part 192 standards are shaded in this table.

(2) Gross α excluding uranium

ND = Not detected.

NS = Not Sampled

Unf. = Unfiltered sample

Fil. = Filtered sample (0.45 micron filter)

Note: Monitoring well locations are shown in Figure 4.

**Table 3 - Shallow Wells**  
**March 2001, June 2001, and August 2002 Sample Results Exceeding**  
**40 CFR Part 192 Groundwater Standards (1)**

	Shallow Wells March 2001			Shallow Wells June 2001	Shallow Wells August 2002
Analyte	Gross Alpha (2)	U-234 + U-238	U-234 + U-238	Gross Alpha (2)	U-234 + U-238
40 CFR Part 192 Standard	15 pCi/L	30 pCi/L	30 pCi/L	15 pCi/L	30 pCi/L
Preparation	Fil.	Unf.	Fil.	Fil.	Unf.
Date	Mar-01	Mar-01	Mar-01	June	August
Units	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L
Well					
LMW-01	24.1	0.1	0.01	22.7	12.5
LMW-03	-16	34.5	30.5	-5	31.1

(1) Results exceeding the 40 CFR Part 192 pCi/L standards are shaded in this table.

(2) Gross  $\alpha$  excluding uranium

Unf. = Unfiltered sample

Fil. = Filtered sample (0.45 micron filter)

Note: Monitoring well locations are shown in Figure 4.

**Table 4**  
**Comparison of Alternatives - Linde Site - Groundwater Operable Unit**

<b>CERCLA CRITERION</b>	<b>ALTERNATIVE 1</b>	<b>ALTERNATIVE 2</b>
	<b>NO ACTION</b>	<b>LIMITED ACTION</b>
<b>Overall Protectiveness of Human Health and the Environment</b>	Not considered to be protective of human health and the environment because, while ARARs are currently met, there are no means to ensure that on-site groundwater is not used.	Protective of human health and the environment because ARARs are currently met and monitoring would continue to verify that ARARs continue to be met. Land use controls would prohibit the use of on-site groundwater, eliminating any potential threat to human health associated with the use of on-site groundwater.
<b>Compliance with ARARs</b>	This alternative currently complies with ARARs, but no monitoring would be conducted to ensure that any non-compliance with ARARs is detected.	This alternative currently complies with ARARs and monitoring would be conducted to verify that ARARs are met.
<b>Long-Term Effectiveness and Permanence</b>	Not effective and not permanent because there would be no means to ensure that on-site groundwater is not used and no monitoring of potential changes in groundwater quality would be conducted.	This alternative is considered effective and permanent. Land use controls would prohibit the use of on-site groundwater and monitoring would be conducted to ensure that any potential changes in groundwater quality are detected. If it is determined through monitoring that ARARs are exceeded, and additional action is required, such action could be taken.
<b>Short-Term Effectiveness and Environmental Impacts</b>	Effective in the short-term because ARARs are met and no action would be taken that would result in environmental impacts.	Effective in the short-term because ARARs are met and no action would be taken that would result in environmental impacts.
<b>Reduction in Toxicity, Mobility, or Volume Through Treatment</b>	There is no reduction in toxicity, mobility or volume of contaminants associated with this alternative.	There is no reduction in toxicity, mobility or volume of contaminants associated with this alternative.
<b>Implementability</b>	Easily implementable because no action is taken.	Relatively easy to implement. The imposition of land use controls and long term monitoring would be moderately complex.
<b>Present Value Cost (\$)</b>	0	\$800,000

## **APPENDIX A**

### **ASSESSMENT OF THE FATE AND TRANSPORT OF MED/AEC-RELATED CONTAMINATION IN GROUNDWATER AT THE LINDE SITE**



## APPENDIX A

### ASSESSMENT OF THE FATE AND TRANSPORT OF MED/AEC-RELATED CONTAMINATION IN GROUNDWATER AT THE LINDE SITE

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## APPENDIX A

### ASSESSMENT OF THE FATE AND TRANSPORT OF MED/AEC-RELATED CONTAMINATION IN GROUNDWATER AT THE LINDE SITE

---

#### 1.0 INTRODUCTION

As described in the FS report, extensive historical information is available concerning MED/AEC-related contamination at the Linde Site<sup>1</sup>, including detailed descriptions of the disposal of MED/AEC-contaminated process waste by injection into the deep aquifer at Linde. The findings of extensive investigations conducted by Oak Ridge National Laboratory (ORNL), Ford Bacon & Davis Utah (FBDU), DOE, and others to determine the nature and extent of MED/AEC-related contamination at Linde are also available, including characterization of surface and subsurface geology and hydrogeology. Historical information and findings of investigations conducted at Linde and its vicinity through 1992 are compiled in the 1993 DOE RI report (BNI 1993).

The March 2000 ROD for the Linde Site (USACE 2000) addresses the remediation of Site soils and buildings, but excludes Linde Building 14 and the soils under Building 14 and Linde groundwater. Specifically, the ROD states, in part, that the original proposed plan for the Linde (Tonawanda) site(s) [by DOE in 1993] proposed that no action was warranted to address on-site groundwater, that USACE further investigated existing information relating to groundwater, and that USACE also concluded that no remediation of groundwater is warranted. The March 2000 ROD further notes, however, that “comments received during the comment period expressed concerns about the sufficiency of the samples relied upon in coming to the conclusion that no remediation of the groundwater is warranted.”

As described in the FS report, in March 2000, USACE conducted meetings with representatives of the NYSDEC, the USEPA, and other interested parties to develop plans for any supplemental investigations of potential MED/AEC-related groundwater contamination at Linde. A detailed plan for acquiring the additional information required was subsequently developed, with review and approval by interested parties. The details of the objectives and scope of the additional investigation, including specific field activities, are provided in the January 26, 2001 SAP and QAPP (USACE 2001). USACE conducted groundwater investigations at Linde in accordance with the FSP and QAPP beginning in January 2001. The results of the 2001 investigation of groundwater at the Linde Site are summarized in the FS report and this Appendix. Details are provided in the 2002 report, *Results of the 2001 Groundwater Investigation at the Linde Site, Tonawanda, New York* (USACE 2002).

In May 2002, representatives of NYSDEC and USACE met to discuss NYSDEC comments on USACE’s January 2002 report and NYSDEC recommendations for further sampling. It was agreed that additional groundwater sampling and soil sampling for additional leaching tests would be conducted. A June 2002 document, *Sampling and Analysis Plan Addendum (SAP Addendum) Linde Groundwater Operable Unit, Tonawanda, New York* (USACE 2002b), developed by USACE and approved by NYSDEC, describes the scope of the additional investigation. Additional investigations were conducted in accordance with the SAP Addendum in August 2002. The results of the 2001 and 2002 investigations are provided in the report, *Results of the 2001 and 2002 Groundwater Investigations at the Linde Site, Tonawanda, New York* (USACE 2003).

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<sup>1</sup> The Linde Site, referred to herein, is the property formerly owned by Linde Air Products Corp, a subsidiary of Union Carbide Industrial Gas, now owned by Praxair, Inc.

The 1993 RI report provides a description of site conditions and site contamination and the fate and transport of MED/AEC-related contamination in groundwater at the Linde Site based on information available at that time. Sections 2 and 3 of this Appendix summarize the findings available in 1993 and serve as the starting point for a further assessment of potential MED/AEC-related contaminant fate and transport in Linde groundwater. The primary purpose of this appendix is to reassess the potential fate and transport of potential MED/AEC-related contamination in groundwater based on updated information including the findings of the investigations by USACE in 2001.

## **2.0 SITE CONDITIONS AND MED/AEC-RELATED GROUNDWATER CONTAMINATION AS PRESENTED IN THE 1993 RI REPORT**

As described above, extensive information concerning Linde Site geology and hydrogeology was available in 1993 and was included in the 1993 DOE RI report for the Tonawanda Site. In this section, pertinent information on Linde Site surface water drainage, topography, geology, hydrogeology, the disposal of radiologically contaminated waste to site groundwater and groundwater quality information available in the 1993 RI report is summarized. Soil contamination identified at the site is also described to provide information relevant to the potential for shallow groundwater contamination due to the presence of contaminated soils on the site.

### **2.1 Summary of Site Characteristics, Geology and Hydrogeology**

#### **2.1.1 Topography and Surface Water Drainage**

The Linde Site is relatively flat and is situated on a broad lowland east of Twomile Creek, a tributary of the Niagara River. Twomile Creek begins south of Linde in a natural channel. Near the southern boundary of the Linde Site flow in Twomile Creek is directed into twin subsurface box conduits, which traverse the Linde Site, underground. Stormwater runoff from Linde is collected in the facility's stormwater sewer system and is discharged to the two conduits. The twin conduits carry Twomile Creek flow northerly, ultimately discharging through two large flow control gates located on the downstream face of the concrete dam that impounds Sheridan Park Lake. The control gates are pressure operated, releasing storm flow from the conduits, when necessary. Downstream of the Sheridan Park Dam, the natural channel of Twomile creek conveys flow in a generally northerly direction to the Niagara River, approximately 2 ¼ miles north of the Linde Site (see Figure 1).

#### **2.1.2 Geology**

The Linde Site is located within the Erie-Ontario Lowland Physiographic Unit of New York. The Erie-Ontario Lowland has significant relief characterized by two major escarpments—the Niagara and the Onondaga. The elevation of the ground surface is approximately 600 ft above mean sea level at the Linde Site.

##### **2.1.2.1 Regional Geology**

Mapping of regional bedrock geology indicates that the Site area is situated on clayey glacial till. Underlying this glacial till is the Camillus Shale of the Salina Group. This Upper Silurian formation is approximately 400 ft thick in the area and consists predominantly of gray, red, and green thin-bedded shale and massive mudstone. Interbedded with the shale and mudstone are relatively thin beds of gypsum, dolomite, and limestone. The Camillus Shale dips southward at approximately 0.8%. The

formation contains broad, low folds with amplitudes of a few feet and frequencies of a few hundred feet. The fold axes are generally oriented from east to west.

#### **2.1.2.2 Site Bedrock Geology**

Boring logs for eight (8) monitoring wells constructed at Linde during the RI show that bedrock was encountered at depths ranging from approximately 82 to 96 ft (BNI 1993). In borings for the construction of three monitoring wells at the Site in 2001, bedrock was encountered at depths ranging from approximately 72 to 85 ft (USACE 2002).

The bedrock encountered (shales of the Salina Group) is generally described as a gray shale and mudstone with abundant thin layers and irregularly shaped masses of gypsum. In some intervals, as thick as 10 ft., gypsum constitutes as much as half of the rock. The thickest individual gypsum layer found was 1 ft. Generally, gypsum is present in only small amounts, as joint and fracture fillings.

The RI report indicates that all boreholes with significant core recovery showed moderate to extensive fracturing in the upper 6 to 15 feet of bedrock. Cores were noted to be only slightly fractured in most places below this upper zone. Joints were primarily perpendicular to the core axes and parallel to bedding planes. Joint surfaces were mostly planar to gently undulated and slightly rough. Partial to full gypsum crystal development characterized many joints and a few joints were coated with mud. Jointing was found to be common at the contact between gypsum and shale. Core descriptions by field geologists indicate that solution features are relatively common in the bedrock, especially in the gypsum.

#### **2.1.2.3 Site Soils**

Based on numerous soil borings, the RI report indicates that the natural soils at Linde appear to be covered by a fill layer ranging in thickness from 0 to 17 ft. As noted in boring logs, the fill contains substantial quantities of slag and fly ash that was apparently brought on-site from local sources for grading purposes during the construction of the Linde facility.

Undisturbed soils that underlie the site are composed primarily of clay and sandy clay. These soils have low permeabilities precluding significant infiltration of precipitation.

### **2.1.3 Groundwater**

#### **2.1.3.1 Regional Hydrogeology**

Information on regional hydrogeology available in the RI report indicates that the unconsolidated materials contain the most productive water-bearing zones in the Niagara Region. These materials have a wide range of hydrogeologic properties, caused by variations in thickness, distribution and lithology. In areas where relatively thick sequences of coarse-grained glaciofluvial deposits are present, well yields as much as 700 gallons per minute (gpm) are reported.

The soluble limestone and dolomites of the Salina Group and the overlying Onondaga Formation are considered to be a single aquifer. Groundwater within this aquifer is controlled by secondary porosity features (i.e., fractures, joints, and bedding plane openings). These discontinuities have been enlarged by the solutioning of gypsum by groundwater. Wells completed in this aquifer can yield as much as 300 gpm, but generally yield less than 100 gpm. Groundwater obtained from this aquifer is generally potable except where groundwater has been degraded by upward movement of mineralized water from the underlying shales of the Salina Group.

The Camillus Shale (shales of the Salina Group) is the most productive bedrock aquifer in the region. Water in this formation is obtained primarily from solution cavities that have formed as the gypsum contained in the rock dissolved. Yields from individual wells of greater than 1,000 gpm from the Camillus Shale are not unusual in the Buffalo-Tonawanda area.

Groundwater in the shales of the Salina Group generally exists under artesian conditions. Records of wells drilled at and near the Linde Site indicate that water rises to a depth approximately 40 ft below the surface of the land in wells completed in the shale. Average hydraulic conductivities measured at these wells are in excess of  $1 \times 10^{-3}$  ft/s ( $3 \times 10^{-2}$  centimeters/second [cm/s]). These relatively high hydraulic conductivities can be attributed almost entirely to the gypsum solution cavities.

Although the shales of the Salina Group constitute the most productive bedrock aquifer in the region (well yields as much as 1,200 gpm), the shales also contain the poorest quality water. Groundwater from these shales has high concentrations of dissolved solids, calcium, magnesium, sulfate and chloride. In the vicinity of the Linde Site, waters drawn from wells completed in the shale typically have total dissolved solids contents ranging from 2,000 to 6,000 milligrams/liter (mg/L), sulfate contents of 1,000 to 1,500 mg/L, and chloride contents of 1,500 to 2,000 mg/L. These high levels of total dissolved solids and salinity (derived from the evaporates) preclude use of this water for potable consumption without extensive, costly treatment. Its use is restricted to certain industries that can tolerate the high salinity and total dissolved solids.

Underlying the Salina Group are the dolomites of the Lockport Formation. Like the Salina Group, the dolomites have secondary porosity developed in open bedding, joints, fracture zones, and solution widened discontinuities. Reported well yields for the Lockport Formation (as much as 110 gpm) are lower than the Salina Group. Because the Lockport Formation contains a gypsiferous zone, the groundwater typically contains high concentrations of sulfate rendering it to be non-potable.

#### **2.1.3.2 Site Hydrogeology**

At the Linde Site, the most productive water-bearing zone is comprised of the coarse-grained basal zone of the unconsolidated deposits and the fractured and jointed upper part of the Salina Group bedrock. This zone is collectively referred to as the contact-zone aquifer. .

Information on the contact-zone aquifer is based on data from a total of 19 deep boreholes/wells across the Tonawanda properties (i.e., 11 at Ashland 1 & 2 and 8 at Linde). Data from the 19 deep boreholes/wells indicate that groundwater in the contact-zone aquifer is under confined conditions. At the Linde Site, groundwater rose 40-50 ft above the contact zone.

Recharge to the contact-zone aquifer probably occurs at several locations. For example, carbonate rocks that constitute an aquifer to the south are exposed (or are minimally covered by unconsolidated material) 3.5 to 4.5 miles southeast of Linde. Also, coarse-grained alluvial deposits along Ellicott Creek, approximately 6 miles east of Linde, may be hydraulically connected to the contact zone aquifer.

At Linde, the piezometric surface appears to slope gently to the southwest. Projections of piezometric contours suggest that the low heads probably existed in the industrial area along Sheridan Drive from the Niagara River to Kenmore Avenue. Several high capacity industrial wells were reportedly located in this area including wells owned by Goodyear Tire and Rubber (also referenced as Dunlop Tire and Rubber in the RI report), E.I. DuPont de Nemours and Company (also referenced as E.I. DuPont and Co. in the RI report), and Linde. It is reported that well yields for the industrial wells ranged from 90 to 3,000 gpm (or 0.1 to 4.3 million gallons per day).

As described in the RI report, Linde is generally covered by a thin veneer of coarse-grained fill material (0-4 feet thick) with localized pits, and building foundations that contain fill to depths as great as 17 ft. Undisturbed soils that underlie surface fill material are composed primarily of clay and sandy clay. These clayey soils have low permeability ( $10^{-8}$  cm/sec), which precludes infiltration of significant quantities of precipitation. Water infiltrating through the more permeable disturbed/fill material would tend to saturate the soils above the clayey/undisturbed soil resulting in a perched groundwater system.

Observations made during the RI suggest that the perched system is intermittent and is associated with precipitation events. The perched system is conceptualized as a short flowpath system, representing subsurface movement of water on top of the natural clay surface to local drainages. Due to the complexity and temporal variability of the perched system, the RI report indicates that conventional monitoring wells and monitoring techniques are not feasible.

### **2.1.3.3 Site Stratigraphy and Groundwater Based on Historical and Current Information**

The current understanding of Site stratigraphy and groundwater at Linde, based on past and current (2001 and 2002) information, is summarized in Section 3.1 and depicted in Figure 6 of the FS report. As described in Section 3.1 of the FS report, the contact zone aquifer at Linde includes the unconsolidated material overlying the bedrock and the upper portion of the bedrock, which is fractured. This aquifer is separated from the upper zones by a thick till/clay layer. As also described in the FS report, a shallow, semi-confined system is present from 16 to 40 ft below the ground surface and a perched zone is present within the fill and upper portion of the till. Please refer to Section 3.1 and Figure 6 of the FS report for details.

## **2.2 Ore Processing and Effluent Disposal at Linde in the 1940's**

As described in the RI report, uranium ore processing was conducted at Linde under a MED/AEC contract in the 1940's. A three-step process was used to separate uranium from the uranium ores and tailings in Step I ores and occasional residues (from Step II operations and other MED/AEC processes) were processed to produce uranium oxide; in Step II, uranium oxide was converted to uranium dioxide; in Step III, uranium dioxide was converted to uranium tetrafluoride. Residues from Steps II and III were recycled, whereas Step I produced large amounts of liquid and solid residue. The liquids were discharged into storm sewers, sanitary sewers and into the on-site injection wells.

During the initial operations, the Step I process involved precipitation of uranium using a procedure that involved adding sulfuric acid to a uranium tricarbonat-rich solution and heating it to drive off carbon dioxide; this was followed by adding relatively small amounts of caustic to cause the precipitation. The effluent from this procedure had a pH that allowed its disposal into the sanitary sewer. At the end of 1943, this method of precipitation was abandoned for a direct caustic method of precipitation which resulted in a better product in much less time.

A drawback to this caustic method of precipitation was that the effluent had a high pH and was no longer acceptable for direct disposal into the sanitary sewer system. As an alternative, two options considered were the use of on-site disposal wells or discharge into Twomile Creek. Although the discharge into the creek was approved by the State of New York, a decision was made to use the on-site disposal wells (injection wells) whenever possible and to rely on the Twomile Creek option as a last resort.



## **2.3 Injection Wells**

In April 1944, the company, with approval from MED, began disposing of the wastes in on-site wells. From 1944 to 1946, seven on-site wells were used during various periods of time for disposal of the liquid wastes. Available information suggests that from time to time the wells would plug, overflow, and have to be cleaned or replaced.

The seven wells were located in two main areas; three wells located in the area of Plant No. 1 (present Building 8) and four wells located near the Ceramics Plant (the former Buildings 30 and 38). The locations of the former injection wells are shown in Figure 2. (Locations of USACE soil samples in 2001 and 2002 are also shown in Figure 2. USACE soil sampling and leaching tests in 2001 and 2002 are described in Section 4 of this Appendix.) It is reported that the injection wells ranged from approximately 90 to 150 ft in depth and were drilled into bedrock.

## **2.4 Liquid Effluent, Volume and Characteristics**

### **2.4.1 Effluent Volumes**

Neither the RI report nor other reports provide information on the volumes of effluent that were discharged to each of the individual injection wells but the RI report indicates that the total estimated volume of effluent discharged into the injection wells was approximately 55 million gallons. Backup for this estimated volume is provided in the Aerospace report (Aerospace 1981) which was based on information from various sources including weekly progress reports.

### **2.4.2 Effluent Characteristics**

Information provided in the Aerospace report (Aerospace 1981) indicates that the filtrate discharged into the sewer or wells was a high pH solution (above a pH of 10) consisting mainly of ions from excess sodium sulfate, sodium carbonate, and sodium hydroxide. In addition, some chloride ions from the barium chlorides added to enhance radium recovery would also have been present, along with a small amount of a variety of complex anions of the many minor elements such as vanadium, nickel and cobalt. Small concentrations of uranium and radium were also present. The Aerospace report indicates that an analysis of the solubility of various radium compounds suggests that a significant portion of the radium and probably the uranium in the effluent would be soluble.

The Aerospace report provides information on the concentrations of uranium and radium in the liquid effluent based on information derived from Linde records including weekly progress reports and memoranda. Information on uranium and radium concentrations in the effluent are summarized below.

The weekly averages of uranium oxide concentrations in the effluents analyzed from April 1944 to July 1946 (from progress reports) ranged between 0.011 and 0.064 grams of uranium oxide per liter of effluent, with the average being about 0.026 grams per liter (g/L). This indicates that the process lost an average of about 26 kg of uranium oxide per million liters or 220 lbs of uranium oxide per million gallons of effluent during the period when the wells and storm sewer were being used. Assuming these loss rates from 55 million gallons of effluent disposed of in the wells, about 12,000 lbs of uranium oxide (about 3 Ci of natural uranium, based on  $6.77 \times 10^{-7}$  Ci/g of natural uranium) were discharged to the injection wells.

While not specifically calculated in the Aerospace report, based on a specific activity for natural uranium of  $6.77 \times 10^{-7}$  Ci/g and an estimated discharge of 3 Ci of natural uranium to the wells, approximately

9,750 lbs of natural uranium would have been discharged in the effluent injected into the wells. At a density (specific weight) of about 1,165 lbs per cubic ft (cf), approximately 8.4 cf of natural uranium would have been discharged to the wells.

The 1981 Aerospace report (Aerospace 1981), the principal source of information on the injection of MED waste at Linde, states that only limited data are available regarding the radium concentrations in the effluent injected. Radium concentrations in the effluent were reportedly maintained at levels below  $2.5 \times 10^{-5}$   $\mu\text{Ci/mL}$  ( $2.6 \times 10^4$  pCi/L) and it is believed that the radium concentrations in the effluent averaged about  $2.5 \times 10^{-6}$   $\mu\text{Ci/mL}$  ( $2.5 \times 10^3$  pCi/L).

The discharge of 55 million gallons of waste with an average radium concentration of  $2.5 \times 10^3$  pCi/L would mean that about 0.52 Ci of radium was discharged to the wells at Linde. Since the specific activity of radium is about 1 g/Ci, about 0.5 grams of radium would have been discharged. If it is assumed that radium was continually present in the waste effluent at the limit of  $2.6 \times 10^4$  pCi/L, about 5.4 Ci (5.4 g) of radium would have been discharged to the wells.

## **2.5 Groundwater Investigations and Findings Through 1993**

A number of investigations were conducted at Linde prior to the 1993 RI report addressing potential impacts to groundwater associated with operations at Linde. This section provides a brief summary of those investigations and their findings. Only summaries are provided. Details are available in the original documents.

### **2.5.1 April 1981 - Linde/Argonne National Laboratory (ANL)**

In April 1981, a number of samples were collected by Linde and analyzed by ANL to characterize the condition of groundwater in the area of the injection/disposal wells. Samples were taken from two test wells, one drilled near Building 8 and the other near Building 38, and from an old gas well near Building 77. Samples were also taken from an industrial well located approximately 2 km (1.25 miles) west of the Linde facility. The old gas well referred to was not used for waste disposal. The 1981 Aerospace report indicates that this well is more than 3,200 feet deep and, therefore, the results of sampling this well are not appropriate for comparison to results of sampling the other wells, which range in depth to a maximum of 150 feet.

Table 1 summarizes the results obtained from the Argonne analysis.<sup>2</sup> Also included in the table are the Nuclear Regulatory Commission (NRC) limits in effect in 1981 for the release of water to an unrestricted area [CFR, Title 10, Part 20, Appendix B, Table 11, Column 2]. A comparison of the average concentrations measured in each well with the NRC limits indicates that all of the average concentrations in the samples were below the NRC limits. Concentrations of all radionuclides dissolved in the water were lowest in the industrial well 1.25 miles west of the site. Dissolved uranium and radium concentrations were highest in the well near the southeast corner of the site (near Building 77).

Concentrations of radionuclides in suspended solids were, with the exception of radium, the lowest in the sample from the industrial well located west of the Linde site. Uranium concentrations were the highest in samples taken from the test well near Building 8, at the location of the disposal wells near Plant No. 1. The test well in the area of the other four disposal wells at the former Ceramics Plant contained

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<sup>2</sup> Note: the results of the analyses are reported in units of  $\mu\text{Ci/mL} \times 10^{-8}$ . To convert  $\mu\text{Ci/mL} \times 10^{-8}$  to the more familiar pCi/L units, multiply by a factor of  $10^9$ .

concentrations greater than the offsite well, but did not have nearly as high uranium or thorium concentrations as the test well near Plant No. 1 (Building 8).

The old gas well, near Building 77, had a greater than expected concentration of uranium in the suspended solids of nearly 110 pCi/g. In evaluating this result, references were quoted in the Aerospace report regarding the concentrations of uranium in carbonate rocks. The reference to the 1969 publication by Rogers and Adams quoted in the Aerospace report indicates that uranium concentrations in carbonate rocks is relatively constant and averages about 1.5 pCi/g, with a maximum of about 12 pCi/g. The Aerospace report points out that the old gas well is deep and extends through a number of formations and that it is unlikely that the shales or sandstones would approach any concentrations near 100 pCi/g. However, it is postulated in the Aerospace report that it is possible that the high concentrations of uranium in the suspended solids could be the result of selective dissolution of the major constituents in the rocks.

### **2.5.2 June 1981 - Oak Ridge Associated Universities (ORAU)**

Additional measurements of groundwater were made by ORAU in June 1981. Samples were collected and analyzed from the two test wells and a residential well located 1.25 miles north of the Linde facility. In general, the analysis (Table 2) confirmed the previous results and indicated that concentrations of radionuclides were within the NRC limits in effect at that time.

### **2.5.3 June 1981 - Ford Bacon and Davis Utah, Inc. (FBDU)**

FB&DU collected three groundwater samples from boreholes at Linde. The results of the analysis of the samples are presented in Table 1-2 of the RI report. The results are reported as average concentrations for the three samples. (Data for individual locations were not provided.) The data presented in the RI report are summarized in Table 3.

The averaged radium concentration for the groundwater samples was reported in the RI report as being below the lower limit of detection of 0.6 pCi/L for the analysis system used; however, the summary table indicates that the average concentration was at the 0.6 pCi/L detection limit. The average U-238 concentration was about 70 pCi/L.

### **2.5.4 December 1981 - The Aerospace Corporation**

The 1981 Aerospace report (Aerospace 1981) discusses the fact that the DOE had numerous samples of soil, water and sediment collected and analyzed to verify that no hazard existed at that time and to determine if any remedial actions were warranted. The report references the work and data of previous studies (i.e. Oak Ridge Associated Universities, Argonne National Laboratory, and Oak Ridge National Laboratory).

The Aerospace report provides a summary of the analysis of groundwater samples collected from wells at the site (summarized in Table 4) which indicate that groundwater beneath the Linde facility contains above-background concentrations of some of the radionuclides; however, concentrations in the groundwater were below the NRC acceptance criteria for release to an unrestricted area. The report notes that due to the very high natural mineral content of the groundwater, it is not acceptable as drinking water or for many other industrial or residential uses; hence, no significant pathway exists for exposure to the general public.

### **2.5.5 DOE RI**

The RI at the Tonawanda properties was conducted in two phases. Both phases involved activities related to the former injection wells. The objectives of the first phase of the RI, as they relate to the former injection wells, were to: 1) investigate the stratigraphy of the properties; and, 2) quantify contaminant concentrations near injection wells. The objective of the second phase of the RI was to determine the extent of deep subsurface radioactive contamination near the former injection wells. The activities associated with each phase and the related findings are summarized below.

#### **2.5.5.1 1988-1989 - First Phase RI**

Eight boreholes were drilled across the Linde site; two of the boreholes (B29W09D and B29W10D) were drilled near the former effluent injection wells. Monitoring wells were constructed in each of the boreholes. Locations of the 8 boreholes are shown in Figure 2. Table 5 summarizes borehole information. The summary table also includes information available on the injection wells. A comparison of the available injection well data to the 8 borehole/monitoring well data indicates the 8 boreholes were drilled to approximately the depth of the 3 injection wells from which there is data; however, the screened intervals for some of the monitoring wells appear to have been higher than the injection zone for the injection well at the Ceramics Plant. The screened intervals for the monitoring wells are also much smaller than the injection zones being limited to the upper portion of bedrock (i.e., 6 to 15 feet into rock). Monitoring well 11D is actually screened in the coarse-grained basal zone of the unconsolidated deposits. However, hydraulic conductivity data (refer to Table 6) suggests that the upper 15 feet of bedrock is more permeable than the deeper zones tested.

Groundwater samples were collected from these 8 monitoring wells following construction. (The monitoring wells were not purged prior to sampling.) The results of the analysis of these samples are presented in Tables 4-64 through 4-67 and 4-69 through 4-73 of the RI report. The RI report states that data analysis and validation performed during preparation of the RI report identified possible sources of error in the data for deep wells at Linde, noting that the deep wells at Linde were not purged before samples were collected.

Resampling of one of the monitoring wells (B29W09D) near one of the injection wells was subsequently conducted. Before it was sampled, this well was redeveloped. Two sets of groundwater samples were collected from B29W09D following redevelopment: one sample prior to purging and a second sample following well purging. The radiological results of the resampling/validation sampling are presented on Table 7 along with the radiological results from quarterly sampling conducted in 1989 and 1990. Resampling/validation sampling results for well B29W09D indicate that Total Uranium and Ra-226 concentrations were below the standards in Subpart A of 40 CFR 192.

#### **2.5.5.2 1990-1991 - Second Phase RI**

The second phase of the RI involved drilling two deep boreholes (LIWRO-01 and LIWRO-02) offset from a monitoring well (B29W10D) near one of the injection wells. Locations of these two deep boreholes, monitoring well B29W10D, and one of the three former injection wells near Building 8 (formerly referred to as Plant No. 1) are shown in Figure 2. The purpose of the deep borings was to confirm the elevated radioactivity noted in the core sample from B29W10D and provide access to the injection zone of one of the former injection wells near Building 8.

Well LIWRO-01 was drilled to a depth of 119 ft at a location approximately one foot away from an old injection well. Well LIWRO-02 was drilled to a depth of 105 feet at a location approximately 10 feet further away from the injection well. The RI report states that during drilling of LIWRO-01, adjacent wells reacted to drill water circulation. Fill material in the closest injection well subsided 6 feet during drilling, and gas bubbled out of the water in the small injection well. The bubbles ceased when drilling stopped, indicating a hydraulic connection between the injection wells and LIWRO-01.

During drilling, the core material from the two boreholes was scanned for beta-gamma activity. A core sample from LIWRO-01 showing elevated radioactivity was collected and analyzed for thorium-230, thorium-232, radium-226, and uranium-238. U-238 (176 pCi/g), Ra-226 (1.3 pCi/g) and Th-232 (0.4 pCi/g) were detected. The core was noted to have a visible layer of yellow material within a small fracture zone. Both boreholes were gamma-logged with a shielded sodium-iodide (thallium) downhole probe. Gamma logging of LIWRO-01 identified three thin intervals with elevated gamma readings. All elevated gamma readings were encountered within the upper 15 feet of the weathered bedrock section at depths of approximately 92, 100 and 102 ft below the ground surface. The elevated gamma reading at approximately 100 ft corresponds with the approximate depth at which a 10 mm thick yellow precipitate material was identified in the rock core from LIWRO-01.

## **2.6 Radioactive Contamination in Site Soils**

The RI report describes elevated levels of radionuclides in the Linde Site soils. Remediation of site soils has been underway since June 2000 and the following describes pre-remediation conditions.

The RI report indicates that U-238, Ra, 226, and Th-230 are the primary MED/AEC-related radionuclides of concern in the surface and subsurface soils at Linde and identifies contamination in four (4) areas of the Site as follows:

**Area 1** contains primarily surficial radioactive contamination located in the northwest corner of the main parking lot area at Linde. The RI report indicates the contamination does not extend deeper than 4 ft.

**Area 2** contains primarily surficial contamination located along the northern boundary of Linde and the northeastern corner of the main parking area. A temporary storage pile for the consolidation of radioactively contaminated soils and windrow materials is located in this area. Contamination does not extend deeper than 1.2 m (4 ft). (This material has now been removed from the Linde Site.)

**Area 3** is located along the fence line in the northeastern corner of the property. Evidence of radioactive contamination in this area extends off the property and encompasses a railroad spur formerly used to haul uranium ore into Linde. Sampling results show that the radioactive contamination is present to a depth of 4 ft in the area west of the railroad tracks and to a depth of 2.0 ft east of the tracks.

**Area 4** includes the areas of Buildings 30, 31, 38, 58, and a blast wall outside Building 58. Sampling results show that the soil beneath Building 30 is radioactively contaminated to a depth of 2.4 m (8 ft).

Several remedial actions have been conducted at Linde since the 1993 RI and FS reports were prepared. These remedial actions included the demolition of Buildings 38 and 30 and the decontamination of Buildings 31 and 14.

A subsurface investigation at Buildings 31 and 57 was conducted in 1996. Results of the investigation indicate the presence of radioactive contamination in soils at locations not reported in the 1993 DOE documents, including contamination under Building 57.

Decontamination of Building 14 was completed in 1998, including removal of radioactively contaminated soils from beneath floor slabs. A small, inaccessible volume of radioactively contaminated soils were left under structural support members. Building 14 and the soils under the building are being addressed under separate CERCLA documentation.

As detailed in the USACE Technical Memorandum: *Linde Site Radiological Assessment* (USACE 2000), the 95 percent upper confidence limit values for radiological contamination in site soil used in the assessment of risks ranged from 0.88 pCi/g to 41.7 pCi/g for Ra-226, from 2.5 pCi/g to 82.4 pCi/g for Th-230, and from 30 pCi/g to 197 pCi/g for U-238. Results of analyses of individual soil samples ranged from background to in excess of 1,800 pCi/g for total uranium, from background to in excess of 200 pCi/g for Ra-226, and from background to in excess of 800 pCi/g for Th-230.

For purposes of the radiological assessment, the Linde Site was divided into twelve (12) assessment units. The location of the assessment units where contamination exceeded site cleanup criteria and the locations of samples exceeding the site cleanup criteria are shown in Figure 3.

## **2.7 Ongoing Remediation at the Linde Site**

As noted above, remediation at the Linde Site, in accordance with the 2000 ROD, has been underway since June 2000. The following excerpts from the 2000 ROD describe the remedial actions underway and the criteria used in cleanup of site soils.

“USACE has determined that the cleanup standards found in 40 CFR Part 192, the standards for cleanup of the uranium mill sites designated under the Uranium Mill Tailings Radiation Control Act (UMTRCA) and the Nuclear Regulatory Commission (NRC) standards for decommissioning of licensed uranium and thorium mills, found in 10 CFR Part 40, Appendix A, Criterion 6(6) are relevant and appropriate for cleanup of MED-related contamination at the Linde Site. The major elements of this remedy will involve excavation of the soils with contaminants of concern (COCs) (radium, thorium and uranium) above the soil cleanup levels and placement of clean materials to meet the other criteria of 40 CFR 192, and cleanup of contaminated surfaces in buildings with COCs above the surface cleaning levels.”

“Compliance with these standards will require USACE to: (1) Remove MED-related soil so that the concentrations of radium do not exceed background by more than 5 picocuries per gram (pCi/g) in the top 15 centimeters (cm) of soil or 15 pCi/g in any 15 cm layer below the top layer, averaged over an area of 100 square meters ( $m^2$ ); (2) Remediate occupied or habitable buildings so that an annual average radon decay product concentration (including background) does not exceed 0.02 Working Level (WL) and the level of gamma radiation does not exceed the background level by more than 20 microrentgens per hour; (3) control the releases of radon into the atmosphere resulting from the management of uranium byproduct materials to not exceed an average release rate of 20 pCi/meter<sup>2</sup> second ( $m^2s$ ); (4) removal of MED-related soils with residual radionuclide concentrations averaged over a 100 square meter area that exceeds unity for the sum of the ratios of these radionuclide concentrations to the associated concentration limits, above background, of 554 pCi/g for total uranium, 5 pCi/g for radium-226 (Ra-226) and 14 pCi/g for thorium-230 (Th-230) for surface cleanups and 3,021 pCi/g of total uranium, 15 pCi/g of Ra-226 and 44 pCi/g of Th-230 for subsurface cleanups; (5) In addition, consistent with the proposed plan released for public comment in March 1999 prior to promulgation of the amendment to 10 CFR Part 40, Appendix A, Criterion 6(6) in June 1999, USACE will remediate the Linde Site to insure that no concentration of total uranium exceeding 600 pCi/g above background will remain in the site soils; and (6) removal of MED-related residual radioactive materials from surfaces necessary to meet the benchmark dose for surfaces of 8.8 mrem/y based on the specific location of the surfaces and exposure

scenarios. Appropriate as low as reasonably achievable (ALARA) principles will be included in the detailed site remediation plan.”

“Verification of compliance with soil cleanup standards and criteria will be demonstrated using surveys developed in accordance with the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) and as may be required by the ARARs.”

“The selected remedy will involve the demolition of buildings necessary to remediate the site. These buildings include Buildings 57, 67, 73, 73B, 75 and 76 and will also include the building slabs and foundations. The slabs that are remaining after the demolition of Buildings 30 and 38 and the tank saddles north of Building 30 will also be removed. A wall in Building 31 will be removed to access sub-slab and sub-footing soils exceeding criteria. Soils and surfaces containing MED-related contamination will be remediated in order to meet the ARARs. The final remediation of Building 14 and soils under Building 14 has been excluded from this ROD, to be addressed separately in the future.”

“The selected remedy will also include remediation of the adjacent Niagara Mohawk and CSX Corporation (formerly Conrail) properties, where radioactive contamination has already been identified or may be identified as the remediation work is implemented. The remediation is limited to following releases that originated from the Linde Site resulting from MED-related operations. The plan also includes the removal of contaminated sediments from drainlines and sumps, the removal of contaminated soil from a blast wall structure located east of Building 58 and remediation of a subsurface vault structure located just west of Building 73.”

Remediation of the Linde Site in accordance with the 2000 ROD is scheduled for completion in 2007.

### **3.0 CONCEPTUAL MODEL OF THE FATE AND TRANSPORT OF MED/AEC-RELATED CONTAMINATION IN GROUNDWATER BASED ON INFORMATION AVAILABLE IN 1993**

This section summarizes the conceptual model developed in the RI report for the fate and transport of MED/AEC-related contamination in groundwater at the Linde Site. Deep groundwater and shallow groundwater are addressed.

#### **3.1 Contaminant Fate and Transport in Deep Groundwater**

##### **3.1.1 Overview of Findings and Conclusions on Contaminant Fate and Transport from the RI Report**

The RI report notes that approximately 55 million gallons of liquid waste effluent, containing 11,900 lb of dissolved uranium oxide, was injected into the subsurface at Linde in the 1940's. The RI report states that this effluent, which contained primarily ions of sodium, sulfate, sodium carbonate, sodium bicarbonate, and chloride, was injected at a temperature of approximately 60°C (140°F). Minor concentrations of vanadium, cobalt, nickel, molybdenum, uranium, and radium were also present in the effluent. This injected liquid had a pH above 10 and a total dissolved solids (TDS) concentration greater than 20,000 mg/L. The RI reports notes that natural formation water in the bedrock units contains significantly lower concentrations of the major ions and TDS (2,000 to 6,000 mg/L); the water temperature is 12°C (54°F); and the pH is approximately neutral (7.0 to 7.5).

The waste effluent was injected into the subsurface at depths ranging from 90 to 150 ft. The RI report indicates that problems were reported with well plugging and fluid refusal during the injection process, and liquid effluent could have moved into the upper portion of the bedrock unit (described as fractured and heavily weathered shales of the Salina Group) and up the annular space around the well casing into the glacial unconsolidated sediments overlying the bedrock surface. According to the RI report, these problems resulted from the formation of precipitates in the fractures and pore space of the sediments when the heated effluent (with high pH and elevated concentrations of dissolved solids) mixed with the natural formation water. Although sulfate- and carbonate-rich minerals of the various metals formed the majority of the precipitates, this process would also have stabilized the majority of the dissolved metals (including uranium and radium) in the solution. Elevated concentrations of chloride, sodium, and sulfate are still present in the formation fluids underlying the property.

The estimated volume of effluent injected (55 million gal) equals 168 acre-ft of fluid. Assuming the fluid entered a 20 ft interval of the sedimentary section having an average porosity of 10 percent (a conservative assumption – glacial tills and sands commonly have porosities in the 20 to 30 percent range), the area impacted would be approximately 84 acres. If a higher porosity were assumed, the area impacted would be reduced accordingly.

A local flow velocity of 1.7 to 7.3 m/yr (5.5 to 24 ft/yr) was estimated based on regional groundwater flow in the Salina Group shale and limited water level data. (Section 5.1 describes the principles used in estimating the velocity of groundwater.) This velocity would indicate that the injected fluid remains in the local area, having moved approximately 90 m (300 ft) since the time of injection. Using conservative assumptions, the maximum area of impact may have been as large as 168 acres, with lateral movement of up to 1,300 ft.

Based on the above scenario, the nature of the subsurface contamination is probably in the form of mineral precipitates of uranyl sulfates and carbonates in the fractures and pore space of the Salina Group shale. Groundwater of this shale in the immediate proximity of the property exhibits elevated concentrations of sodium, sulfate, and chlorides and has a higher pH (9+) than the natural formation water. The generally low permeability of the shale and the computed flow velocities indicate that no significant migration of the contaminants from the immediate area has occurred.

Figure 4 of this appendix, adapted from the RI report, illustrates the fate of liquid wastes injected at Linde.

### **3.1.2 Additional Details - Contaminant Transport**

The RI report describes the MED-related contaminants at the site as being uranium-238 (U-238), Ra-226, Th-230, and metals. The report summarizes the properties that govern radionuclide fate and transport as being radioactive decay rate, solubility, and sorption in soils and notes that, with the exception of radon, the radionuclides of interest at the Tonawanda Site have half-lives of more than 1,600 years and are, therefore, very stable.

The RI report explains that a distribution coefficient ( $K_d$ ) relates a radionuclide concentration in water to that in soil and further notes that a high distribution coefficient means a higher radionuclide concentration in soil and a significantly lower concentration in the groundwater, and, therefore, a lower mobility. (Additional details on the principles of transport of radionuclides and other contaminants in the subsurface are described in Section 5.1.)

Distribution coefficients for thorium and uranium in various types of soils and pH conditions are summarized in the RI report, noting that the distribution coefficients cited are not necessarily



representative of the site. The distribution coefficients reported vary over a range of five to six orders of magnitude.

The RI report notes that because the three primary radionuclides at Tonawanda (especially thorium) have high distribution coefficient values, they would have low aqueous concentrations and should be immobile.

Soluble compounds can dissolve in water and be transported, although the transport rate will be affected by soil adsorption. The solubilities of some of the major compounds containing radium, uranium, and thorium are presented in the RI report. Generally, chlorides and nitrates are highly soluble; hydroxides, carbonates, and sulfates (except thorium sulfate) are sparingly soluble.

The RI report notes that the groundwater at Tonawanda has significant levels of chloride and sulfate ions, as well as naturally occurring ions such as pH-dependent hydroxyl ion and carbonate ion (depending on the rock types). Thus, sparingly soluble compounds of radionuclides such as carbonates, hydroxides (e.g., thorium hydroxide), and sulfates can form. The formation of insoluble compounds limits the concentration of radionuclides in solution, thereby limiting their migration.

The RI report found that chemicals detected at the Tonawanda Site include metals and organics. Metals preserve their total mass and do not undergo degradation; however, they can be transported in the environment. They are also subject to chemical transformation or speciation, which can influence mobility by controlling solubility and adsorption in soils. Most metals do not readily volatilize.

Distribution coefficients of some of the metals are presented in the RI report. The solubility product (SP) of some of the sparingly soluble compounds of metals and radionuclides detected at Tonawanda are also given in the RI report, noting that a lower SP means that the compound is less soluble. The solubility of the metal compounds depends on the pH of the water and the concentrations of major ions present in the water. At increased concentrations of either the metal ion or anions (carbonate, sulfate, and hydroxide), a sparingly soluble compound will precipitate. For example, when thorium hydroxide ( $SP = 3.2 \times 10^{-45}$ ) comes in contact with groundwater, it will precipitate or remain insoluble if it is a precipitate in the original solution. Also, barium sulfate ( $SP = 1.1 \times 10^{-10}$ ) is likely to remain insoluble. Of the compounds that are most likely to form, the chlorides, nitrates, and nitrites commonly are the most soluble, whereas sulfates, carbonates, and hydroxides have low to moderate solubility. Soluble compounds are dissolved in water and transported subject to adsorption. An insoluble compound will remain as a precipitate and limit the overall dissolution of the metal.

Based on the findings summarized above, the RI report concludes that contamination in the contact zone aquifer (deep) is from well effluents at Linde. Only very soluble metals such as molybdenum were detected in this aquifer. The radionuclides, especially uranium, are predominantly in the particulate phase and are immobile and are not likely to migrate significantly.

### **3.2 Contaminant Fate and Transport in Perched and Shallow Groundwater as Described in the RI Report**

Linde is generally covered by a thin veneer of coarse-grained fill material (0 to 4 ft thick) with localized pits and old building foundations that contain fill to depths as great as 17 ft. Undisturbed sediments that underlie the surface fill material are composed primarily of clay and sandy clay. These soils have low permeability, which precludes infiltration of significant quantities of precipitation. Infiltrating water (perched zone) tends to flow laterally along the contact surface of the undisturbed sediments in the fill material and discharges into streams and wetlands where the natural clay materials are at the surface. Subsurface ponding occurs in the buried pits and old building foundations containing fill material. Water

trapped in these areas will percolate downward at a slow rate because of the low permeability of the underlying clays. Flow directions in the fill material generally correspond to the surface topographic configuration. No monitoring wells were installed during the RI at Linde to determine water quality in either the perched or the shallow groundwater.

The RI report describes the principal sources of contamination at Linde as being contaminated surface and subsurface soils, subsurface rock and groundwater contaminated with injected processing effluent, and contaminated structures and equipment. The primary mechanisms of release from the identified sources are percolation and subsequent leaching to groundwater, gaseous and airborne particulate emission, and surface runoff. Shallow groundwater percolation and leaching are addressed.

Excess precipitation (water remaining after surface runoff and depression storage) infiltrates into the ground surface. Some of the infiltrating water is lost to evapotranspiration, and the rest percolates down into the shallow unconsolidated saturated zone or flows horizontally in a perched water system. The rate of infiltration is controlled by soil texture, soil moisture, and hydraulic conductivity of the soil and by meteorological conditions affecting evapotranspiration. As noted earlier, the infiltration rates calculated are 9.4 cm/yr (3.7 in/yr) for Linde. Areas covered by concrete pads or buildings are not considered to have water infiltrating into the soil.

The primary pathway of contaminant transport through subsurface soil is via the perched groundwater system. Because of the natural clays underlying the properties, vertical percolation of recharge water to the shallow groundwater system is minimal; therefore, the potential for contaminant migration to the shallow groundwater system is reduced.

Most of the soil contaminants are confined to surface soils above the natural clays at the properties. Water infiltrating through the contaminated soils may leach contaminants and transport them to the perched groundwater system. The perched system, which follows the contour of the top of the natural clays, transports the contaminants to nearby discharge points in the surface drainage systems. The RI report indicates, however, that sampling of surface water at locations upstream and downstream of the Linde Site was conducted during site characterization activities in 1988 and 1989. Figure 2-18 of the RI report shows sampling locations and the narrative on page 4-29 of the RI report states that "Location 4 should represent water and depositional contaminants that may originate upstream of the property; comparison of the data for locations 1 and 4 should give an indication of the influence of the property on creek water and sediment quality." Table 4-20 of the RI report includes the results of surface water analysis for the presence of radionuclides. The results indicate: U-238 at 4 pCi/L at location 4 (upstream) and U-238 at 2 pCi/L at location 1 (downstream); Ra-226 at 0.6 pCi/L at location 4 and Ra-226 at 0.5 pCi/L at location 1; Th-230 at <0.2 pCi/L at location 4 and Th-230 at <0.1 at location 1. The results of the sampling show surface water not impacted by radionuclides from the Site, when upstream and downstream results are compared. These samples were taken prior to the remediation of soils that has been underway at Linde since 2000, removing hundreds of tons of soil contaminated with radionuclides and greatly reducing any potential leaching of radionuclides to groundwater or contaminant discharge to surface water.

The vertical flow velocity in the perched system is less than 0.09 m/yr (0.3 ft/yr).

The RI report (Table 5-9) gives the vadose zone vertical transport velocities for metals and radionuclides based on  $K_d$  values for a soil-clay matrix. A retardation coefficient for metals and soils was also calculated in the RI report using a bulk density of 1.8 g/cm<sup>3</sup> and a porosity of 0.4. (While not specifically stated in the RI report, the retardation coefficient expresses the relationship between the theoretical velocity of the groundwater and the actual velocity of a contaminant moving through the groundwater system. A high retardation coefficient means that the rate at which the contaminant is predicted to move

is much slower than the theoretical velocity of the groundwater. A retardation coefficient of 1 would mean that the velocity of the contaminant would equal the velocity of the groundwater. Contaminants having a high distribution coefficient will also have a high retardation coefficient in the media of interest.) The vertical transport velocities of contaminants are extremely low because of the high distribution coefficients and the thick clay layer underlying the site. Some of the more mobile contaminants, such as arsenic, boron, and cadmium, move vertically less than 0.003 m/yr (0.01 ft/yr). The solubility of most of the radionuclides and metals is very low, and thorium and several other metals are likely to be present as precipitates; therefore, the potential for migration is further reduced.

The RI report concludes that the results do not indicate that the MED/AEC-related radionuclides and metals are migrating at a detectable rate into the natural clays below the properties.

The perched groundwater system flows horizontally at an average velocity of 33 m/yr (108 ft/yr) at Linde. Next to surface runoff, this is the most important contaminant migration route.

High contaminant retardation and groundwater recharge with a low percolation rate [an average linear velocity of less than 0.3 m/yr (1 ft/yr)] prevent any significant contaminant migration to the shallow aquifer. The vertical velocity of radioactive and metal contaminants through the unsaturated zone is negligible. The RI report concludes that, because of the extremely low rate of flow in the saturated groundwater system, no migration is likely via groundwater discharge.

#### **4.0 FINDINGS OF LINDE GROUNDWATER INVESTIGATIONS IN 2001 AND 2002**

As described in the FS report, the investigations of Linde groundwater in 2001 and 2002 were conducted to supplement the information in the 1993 RI report. The principal investigation activities included:

- construction of 3 new deep monitoring wells and the construction of 3 new shallow monitoring wells;
- three groundwater sampling rounds, with sampling conducted at the new and existing monitoring wells;
- analyses of filtered and unfiltered groundwater samples from these wells for the presence of radionuclides, metals, and analyses of these samples for general chemistry parameters; and
- collection of soil samples for radionuclide analyses and leaching tests.

The description of these and other investigations conducted and their findings are presented in the FS report and in the results report (USACE 2003). A brief description of the results is provided below.

##### **4.1 Construction of Monitoring Wells**

Three deep monitoring wells, LMW-04, LMW-05, and LMW-06, and three shallow monitoring wells, LMW-01, LMW-02, and LMW-03 were constructed at Linde in 2001.

The locations of the new and existing monitoring wells are shown in Figure 2. Table 8 summarizes boring monitoring well details and well development details.

##### **4.2 Groundwater Sampling and Analyses**

Groundwater from the newly installed monitoring wells and the existing monitoring wells was sampled in March and June 2000 and August 2002. Unfiltered samples and filtered samples were analyzed for the

presence of radionuclides including radium isotopes, thorium isotopes, uranium isotopes, , gross alpha radiation, gross beta radiation and total uranium. Unfiltered and filtered samples from the wells were analyzed for the presence of target analyte list (TAL) metals and the samples from the wells were also analyzed for general chemistry parameters.

Prior to sampling, groundwater elevations were gauged (see Table 29) and the wells were purged (see Table 9).

### **4.3 Results of Analyses of Groundwater Samples**

The results of the analyses of the groundwater samples for radiological parameters are summarized in Tables 10 through 17. The results of the analyses of the groundwater samples for metals are shown in Tables 18, 19 and 20. The results analyses for the samples for general chemistry parameters are shown in Table 21.

As described below, the results of the analyses were compared to the groundwater standards of 40 CFR Part 192. Shaded cells in the tables indicate results exceeding the 40 CFR Part 192 standards.

### **4.4 Assessment of Groundwater Results**

The results of the 2001 and 2002 groundwater sampling were compared to the groundwater standards found in 40 CFR Part 192, which are applicable to specific sites designated under UMTRCA. These standards and their relationship to Linde groundwater are described in the FS report

As shown in Table 23, the 40 CFR Part 192 standards include maximum concentrations for radionuclides in groundwater, as follows:

- Combined Ra-226 and Ra-228 – 5 pCi/L
- Combined U-234 and U-238 – 30 pCi/L
- Gross alpha particle activity (excluding radon and uranium) – 15 pCi/L

Also included in the standards are eight toxic metals, arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver; nitrate and molybdenum; and six pesticides/herbicides.

Tables 24 and 25 show the results for gross alpha and Ra-226 in deep and shallow groundwater, respectively.

Tables 26 and 27 summarize the comparison of the deep and shallow groundwater results to the 40 CFR Part 192 standards.

#### **4.4.1 Results of Leaching Tests**

##### **4.4.1.1 Leaching Tests in 2001**

Five (5) soil samples (and one duplicate sample) were collected at the Linde Site on March 8 and 9, 2001. Two samples and one duplicate sample were collected from below the footprint of Building 30. Three samples were collected at a depth of 0.5 to 1.5 ft from an excavation near Building 73B (see Figure 2).

As described in the FS report, these soil samples were subjected to the WET extractions to assess the potential for leaching. The results are shown in Table 28. The WET test is aggressive and represents a

worst case for leaching. The groundwater results near Building 30 (LMW-03) support the conclusions of the leaching tests that there is potential for leaching of radionuclides (uranium) from site soils, but actual groundwater concentrations of uranium are at levels below the 40 CFR Part 192, Subpart A standards. The March 2001 groundwater samples from the shallow wells were taken prior to remediation of the areas surrounding LMW-01 and LMW-03. The March 2001 soils samples had significantly elevated uranium concentrations. The CAL WET leaching analysis showed a high potential for leaching to groundwater, yet this was not supported by elevated readings in LMW-03.

#### **4.4.1.2 Leaching Tests in 2002**

Four (4) soil samples (and one duplicate sample) were collected at the Linde Site in August 2002. Two samples and one duplicate sample were collected from below the footprint of Building 30, in an area (Class 1 area<sup>3</sup>) where active soil remediation activities (soil removal) have occurred or are currently ongoing by USACE. Two additional soil samples were collected from Class 2 areas,<sup>4</sup> located along the northern property line and east of Building 90 (refer to Figure 2). Soil sample LISB0012 was collected from the 12- to 18-inch interval and soil sample LISB0013 was collected from the 0- to 6-inch interval. As described above, these sample locations were based on field screening data of geoprobe samples provided by USACE. The samples are identified in Table 28 and sample locations are shown in Figure 2.

The samples were analyzed for isotopic radium, thorium, and uranium. The samples were also subjected to the CAL WET and modified CAL WET analysis as described in Section 4 of the FS report. The results of soils analyses and analyses of the leachate from CAL WET and modified-WET extractions are shown in Table 28.

As shown in Table 28, soils subjected to the CAL WET extractions show the potential for leaching. Samples subjected to the modified CAL WET show significantly less leaching potential.

For example, sample LISB0010 shows U-238 present in the sample at 0.78 pCi/g. The CAL WET test results show U-238 present in the leachate (extract) at 7.4 pCi/L, and the results of the modified CAL WET show U-238 present at 0.112 pCi/L.

The leaching test results suggest that there is potential for leaching of radionuclides (uranium) from site soils. It is noted, however, that actual shallow groundwater concentrations of uranium are at levels above (<2% to 15% above) or below the 40 CFR Part 192, Subpart A standards.

### **4.5 Groundwater Elevations and Groundwater Flow Direction**

Groundwater elevations in the monitoring wells were gauged in March and June 2001 prior to sampling. The groundwater elevations, referenced to mean sea level, are shown in Table 21. Wells LMW-01, LMW-02 and LMW-03 are shallow wells. The other wells are deep wells.

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<sup>3</sup> Class 1 areas are areas that have, or had prior to remediation, the potential for radioactive contamination in excess of the cleanup criteria, or known radioactive contamination in excess of the cleanup criteria.

<sup>4</sup> Class 2 areas are areas that have not been remediated, that have a potential for radioactive contamination or known contamination, but are not expected to exceed the cleanup criteria.

#### **4.5.1 Groundwater Elevations in Deep Wells**

Figures 7 and 8 of the FS report show the piezometric surface in the deep wells in March and June 2001.

The piezometric contours were developed using the SURFER<sup>®</sup> code which assumes a linear relationship between elevation data points and develops contours to simulate points of equal elevations. The contours are illustrative and may not reflect the actual piezometric elevation at a point between wells or at more distant points

The piezometric contours for the contact zone aquifer, as indicated in the figures, shows the groundwater flow direction to generally be to the southeast in March and to the southwest in June. There are some local anomalous readings, such as the difference in elevations in groundwater gauged in wells B29W10D and LMW-06, which are adjacent to one another. (There was a 0.19 ft difference in these elevations in March 2001 and a 0.39 ft difference in these elevations in June 2001. Monitoring wells B29W10D and LMW-06 are screened at different intervals, which may result in variations in groundwater elevations between these monitoring wells.) Overall, the gradients across the site are small. For example, the water level elevation difference between well B29W07D and B29W05D, located about 2,150 ft southwest, was 0.49 ft in June 2001, or a gradient of 0.0002. The June 2001 groundwater flow direction and gradient information for the deep aquifer determined during the 2001 investigation are generally consistent with the information reported in the 1993 RI report, which indicates that flow in the deep aquifer is to the southwest. The March flow direction data appears to be anomalous. Groundwater elevation measurements in August 2002 were inclusive.

The groundwater elevations observed in the contact zone aquifer are also consistent with the findings of the RI report that the contact zone aquifer is under confined conditions, with the hydraulic head rising 40 to 55 ft above the contact zone.

#### **4.6 Groundwater Elevations in Shallow Wells**

Groundwater elevation data are limited for the shallow wells. The reported groundwater elevations show elevations in the shallow wells 25-30 ft above the elevations indicated for the deep wells in the contact zone aquifer, which is consistent with the presence of a low conductivity layer separating the shallow and deep systems, as reported in the RI report.

### **5.0 CONCEPTUAL MODEL OF CONTAMINANT FATE AND TRANSPORT BASED ON CURRENT INFORMATION**

#### **5.1 Overview of Radionuclide Transport in the Subsurface, Distribution Coefficients and Retardation Factors**

As an introduction to the consideration of the transport of contaminants in Linde groundwater, the following sections describe the principles commonly used in assessing contaminant transport in groundwater.

## 5.1.1 Transport of Radionuclides in the Subsurface

### 5.1.1.1 Physical Characteristics of Subsurface Flow

Transport of radionuclides and other contaminants through subsurface porous material is influenced by the physical and chemical nature of the transporting media (usually water) and the medium through which the flow occurs (soil, rock, etc.). Subsurface porous flow is controlled by two key variables, hydraulic conductivity (also referred to as permeability) and the driving force (also referred to as hydraulic head). The hydraulic conductivity of porous or fractured subsurface material is determined by the volumetric extent of voids or porosity within the material and the rate with which fluids can move from one void-space to another. Flow in the subsurface involving the movement of dissolved constituents caused by the bulk movement of fluids is referred to as advection. Other processes by which constituents are transported include dispersion, diffusion, and phase separation.

The basis of porous media flow hydraulics is Darcy's Law, which states that the flow rate through a porous media is proportional to the head loss and inversely proportional to the length of the flow path. In saturated conditions, and if flow is laminar and without turbulence, Darcy's law is applicable and can be simply stated as:

$$V = Ki$$

where

$V$  = velocity

$K$  = hydraulic conductivity or permeability of the porous medium

$i$  = hydraulic gradient

Using the continuity equation,  $Q$  (rate of flow) =  $A$  (area)  $V$  (velocity), the flow is determined as:

$$Q = KiA$$

The discharge velocity through a porous medium is determined as the volume of water that flows per unit time across a unit cross sectional area. In a porous medium, the flow is only through the void spaces. Therefore, the actual average interstitial velocity or seepage velocity is the discharge velocity divided by the porosity. The actual velocity is:

$$V_{\text{actual}} = \frac{V}{n} \quad \text{or} \quad \frac{Ki}{n}$$

where

$n$  = porosity

If a unit hydraulic gradient is assumed (i.e.,  $i = 1$ ), then actual velocity is:

$$V_{\text{actual}} = \frac{K}{n}$$

Typical values of  $K$  are widely available in the literature for different types of materials and typical values of  $n$  are also available. For clay, a permeability,  $K$ , of  $1 \times 10^{-7}$  cm/s is typical.

The actual characteristics of flow of water through the subsurface is much more complex than described above. The simple principles of idealized porous media flow provide, however, a background for considering the transport of contaminants with water in the subsurface, as described below.

### 5.1.1.2 Chemical Transport in Subsurface Flow

As solutions move through the spaces within subsurface materials, solutes may either be added to or removed from that solution. Which solutes are removed or added, and the quantity and rate at which they are added or removed, is controlled by the geochemical nature of the solution and subsurface matrix.

Processes of potential importance in retarding the flow of chemical species in the migrating fluid include ion exchange, adsorption, complex formation, precipitation (or co-precipitation), oxidation-reduction reactions, and precipitate filtration (ASTM D4319). These geochemical processes may be very complex, and their understanding may require an extensive base of physical and chemical data which are rarely available.

Most subsurface transport models lump the effects of all geochemical reactions into the concept of the distribution coefficient ( $K_d$ ) or related retardation factors ( $R_f$ ).  $K_d$ s and  $R_f$ s are described below.

## 5.1.2 Distribution Coefficients ( $K_d$ ) and Retardation Factors ( $R_f$ )

### 5.1.2.1 Definition of $K_d$

A partition (or distribution) coefficient (or ratio),  $K_d$ , is a factor related to the partitioning of a contaminant between the solid and aqueous phases. A  $K_d$  value is easily inserted into computer models to quantify reduction in the rate of transport of the contaminant relative to the groundwater flow rate, either by advection or diffusion.

$K_d$  is defined as the ratio of the quantity of the adsorbate adsorbed per mass of solid to the amount of the adsorbate remaining in solution in equilibrium. For the reaction



The mass action expression for  $K_d$ , (typically in units of mL/g) is

$$K_d = \frac{\text{Mass of Adsorbate Sorbed}}{\text{Mass of Adsorbate in Solution}} = \frac{A_i}{C_i}$$

where

$A$  = free or unoccupied surface adsorption sites

$C_i$  = total dissolved adsorbate remaining in solution at equilibrium ( $\mu\text{g/mL}$ ), and

$A_i$  = amount of adsorbate on the solid at equilibrium ( $\mu\text{g/g}$ )

Describing  $K_d$  in terms of this simple reaction assumes that  $A$  is in great excess with respect to  $C_i$  and that the activity of  $A_i$  is equal to 1.



### 5.1.2.2 Retardation Factors and Their Relationship to $K_d$ Values

Retardation factors ( $R_f$ ) are commonly used in modeling of transport of contaminants in groundwater. Mathematically, a chemical retardation factor,  $R_f$ , is generally defined as:

$$R_f = \frac{V_p}{V_c}$$

Where

$V_p$  = velocity of water through a control volume

$V_c$  = velocity of a contaminant through a control volume

In general, the retardation term is greater than 1, since the theoretical velocity of the water is greater than the transport velocity of the contaminant.

Knowledge of the  $K_d$ , the media bulk density, and porosity for porous flow allows calculation of the retardation factor. For porous flow with saturated conditions, the  $R_f$  is defined as:

$$R_f = 1 + \frac{P_b}{n_e} K_d$$

Where

$P_b$  = porous media bulk density (mass/volume)

$n_e$  = effective porosity of the media at saturation

As shown in these formulas, if  $K_d$  values are high, the  $R_f$  is high. Physically, this means that rate of transport of a contaminant  $V_c$  will be low in relationship to the theoretical rate of transport,  $V_p$ , of the water.

The estimates of uranium transport in the subsurface at Linde incorporate the principles described above in a more complex approach, as described in Appendix B.

## 5.2 Fate and Transport of Contaminants in the Contact Zone Aquifer

The RI report concludes that liquid wastes containing radioactive constituents were injected into the subsurface in the 1940s and after injection moved under pressure through fractures in the bedrock and into the more permeable contact zone aquifer overlying the bedrock. The RI report further concluded that because the waste was higher in temperature and had a higher pH than the natural groundwater, the radioactive constituents in the waste precipitated to form relatively insoluble solid material within the bedrock fractures and contact zone formation. The RI report then describes the potential for transport of radioactive constituents within the fractured bedrock and contact zone as minimal due to immobility of the constituents and low hydraulic gradients in these formations. In summary, the RI report concludes that the radionuclides have precipitated in the groundwater and are now immobile in the vicinity of the location where injection occurred. In the RI report, the field evidence of the conceptual model for the fate and transport of the injected radioactive constituents in the contact zone aquifer was limited, with only one set of validated groundwater sample results from one well (B29W10D) on one date.

The 2001 field investigation at Linde included the construction of three new deep wells to monitor groundwater quality in the deep aquifer and two rounds of groundwater sampling at the three new deep and the existing eight deep monitoring wells, with validation of all sampling results. The 2001 investigation, thus, provides more complete field information to assess the conceptual model of fate and transport described in the RI report.

The findings concerning the groundwater flow direction and hydraulic gradient in the deep aquifer (groundwater flow southwesterly at a low gradient) determined from the 2001 investigation are consistent with the 1993 RI report.

The results of the analyses of groundwater show elevated levels of some of the radionuclides at wells LMW-06 and B29W10D near the injection wells and at one more distant well, LMW-05, in March 2001, but no elevated radionuclides in samples from the wells in June 2001. The elevated levels of radionuclides detected in March 2001 at these three locations are attributed to the drilling method used to install the wells and the proximity of well B29W10D to new well LMW-06. It is concluded that the June 2001 samples are representative of actual site conditions and elevated levels of radionuclides are not expected in the deep aquifer at Linde. The findings of the 2001 investigation are consistent with the description of the fate and transport of the radionuclides injected into the deep aquifer as described in the RI report.

As detailed in Appendix B, the PHREEQC geochemical model was used to further predict the potential fate of the uranium discharged to the contact zone aquifer at Linde in the 1940s. Site characterization data from the 1993 RI report and findings of the 2001 groundwater investigation were used in the modeling. The results of the modeling indicate that the soluble uranium present in the waste could precipitate under the natural conditions in the contact zone aquifer. The modeling predicts that uranium solubility under site conditions is approximately 0.04 mg/L or approximately 27 pCi/L. The evaluation further notes that groundwater monitoring shows high concentrations of uranium in monitoring well sediments and low concentrations of uranium in the groundwater, supporting the premise that uranium is remaining in the solid phase in Linde groundwater.

As further detailed in Appendix B, estimates of the potential transport of uranium in the contact zone aquifer were made using a one-dimensional transport equation. Estimates assumed two cases, a single pulse source of uranium and a solubility-limited source. Based on these estimates, the assessment indicates that uranium should have been observed in monitoring wells during the 55 years since the injection occurred. Because the uranium has not been observed at the levels predicted, it is concluded that the premise is supported that the uranium has low solubility in the contact zone aquifer at Linde. This is consistent with the findings of the 1993 RI report.

Significantly, the geochemical model indicates that uranium concentrations under Site conditions would be expected to be approximately 27 pCi/L, which is less than the 40 CFR Part 192 standard. Accordingly, notwithstanding the potential transport of uranium that may be occurring, the concentration of uranium is not expected to exceed the standard.

### **5.3 Fate and Transport of Contaminants in Shallow Groundwater**

As summarized above, the RI report describes the fate and transport of radionuclides in shallow groundwater in terms of potential horizontal flow with discharge to surface water, with a relatively impermeable layer precluding flow and contaminant transport vertically. No monitoring wells were installed in the shallow aquifer as part of the RI. Therefore, no field evidence of actual groundwater quality in the shallow aquifer was available at the time the RI report was prepared.

The 2001 investigation at Linde included the installation of three shallow monitoring wells and two rounds of sampling. Water quality data is not available for one of the wells (LMW-02), due to the low recharge rate for this well. The results from one of the shallow wells, LMW-03 showed the U-234+U-238, 40 CFR Part 192 standard of 30 pCi/L exceeded in unfiltered and filtered samples (<15% and 2% above the standard, respectively) collected in March, but not exceeded in the June 2001 samples.

Soil samples collected at Linde were subjected to leaching tests. The California WET was used. The results show that under the aggressive test conditions employed in the WET, radionuclides, especially uranium, may be leached from the soil. A comparison was made between radionuclide concentrations in soil samples and leachate samples. On average, approximately 39% of the U-238 in soil leached into solution using the CAL WET procedure. When compared to the modified CAL WET procedure, the average percentage of U-238 that leached into solution is much less (approximately 3%). Leaching under actual conditions is expected to be much less than the concentrations observed in these aggressive tests.

The presence of elevated uranium in the results of analyses of groundwater samples from well LMW-03 indicates that uranium is likely leaching from soils in the area. The area of LMW-03 is in close proximity to the Building 30 area where active soil remediation is underway and where soils contaminated with uranium at levels exceeding 10,000 pCi/g were still present at the time of sampling. Accordingly, the sample from LMW-03 would not be representative of post-remediation conditions after soil remediation is complete. When the samples from LMW-03 were taken, soils in the vicinity of LMW-03 had yet to be completely removed to the remedial action criteria for soils established for the Linde Site.

Given that the uranium levels seen in the groundwater from well LMW-03 are in excess of the 40 CFR Part 192 standard in March (<15% and 2% above the standard) and not exceeded in June, it is not likely that the standard will be exceeded in the future after soil remediation is completed.

Results of sampling and analyses of shallow groundwater for the presence of metals and general chemistry parameters shows the presence of elevated levels of sodium, chloride and TDS in shallow groundwater from LMW-01 and elevated levels of sulfate and TDS in shallow groundwater from LMW-03.

The levels of chlorides, sodium and TDS in LMW-01 are among the highest reported in any of the data for Linde groundwater. The source of the elevated sodium and chloride and resultant elevated TDS at this location is not fully known. It may be partially explained if it assumed that effluent being injected into the deep aquifer years ago was allowed to overflow in the shallow system and migrate to this location. However, since elevated levels of sulfate and radionuclides were not detected at this location, it is not concluded that elevated sodium and chloride at this location resulted from effluent injection overflow. More likely explanations are that the use of salt for deicing may be impacting groundwater at this location or that fill material used at the site, said to be more than 17 feet at some locations, results in local impacts to groundwater, exacerbated by the on-going soil removal actions at Linde.

## **FIGURES**

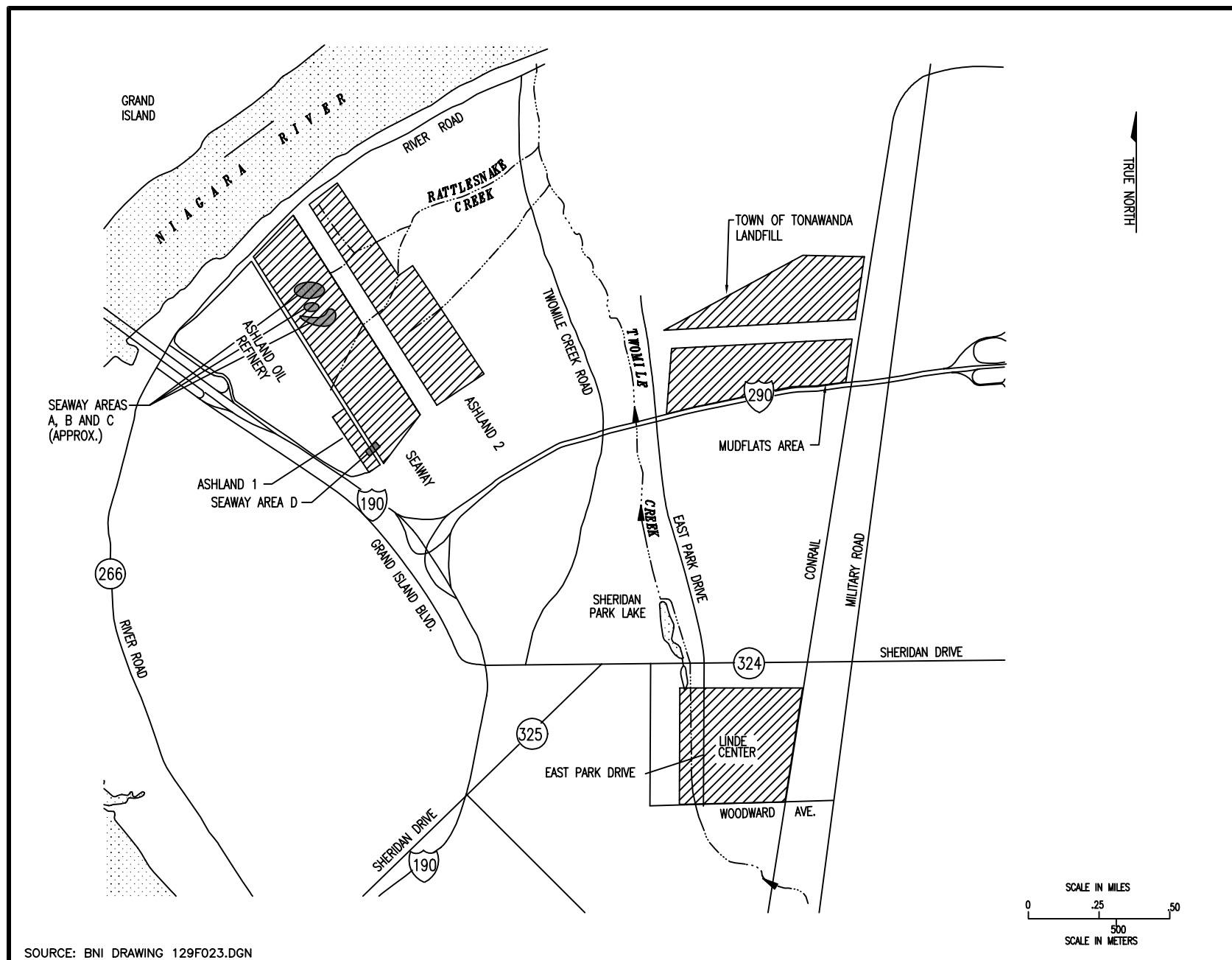
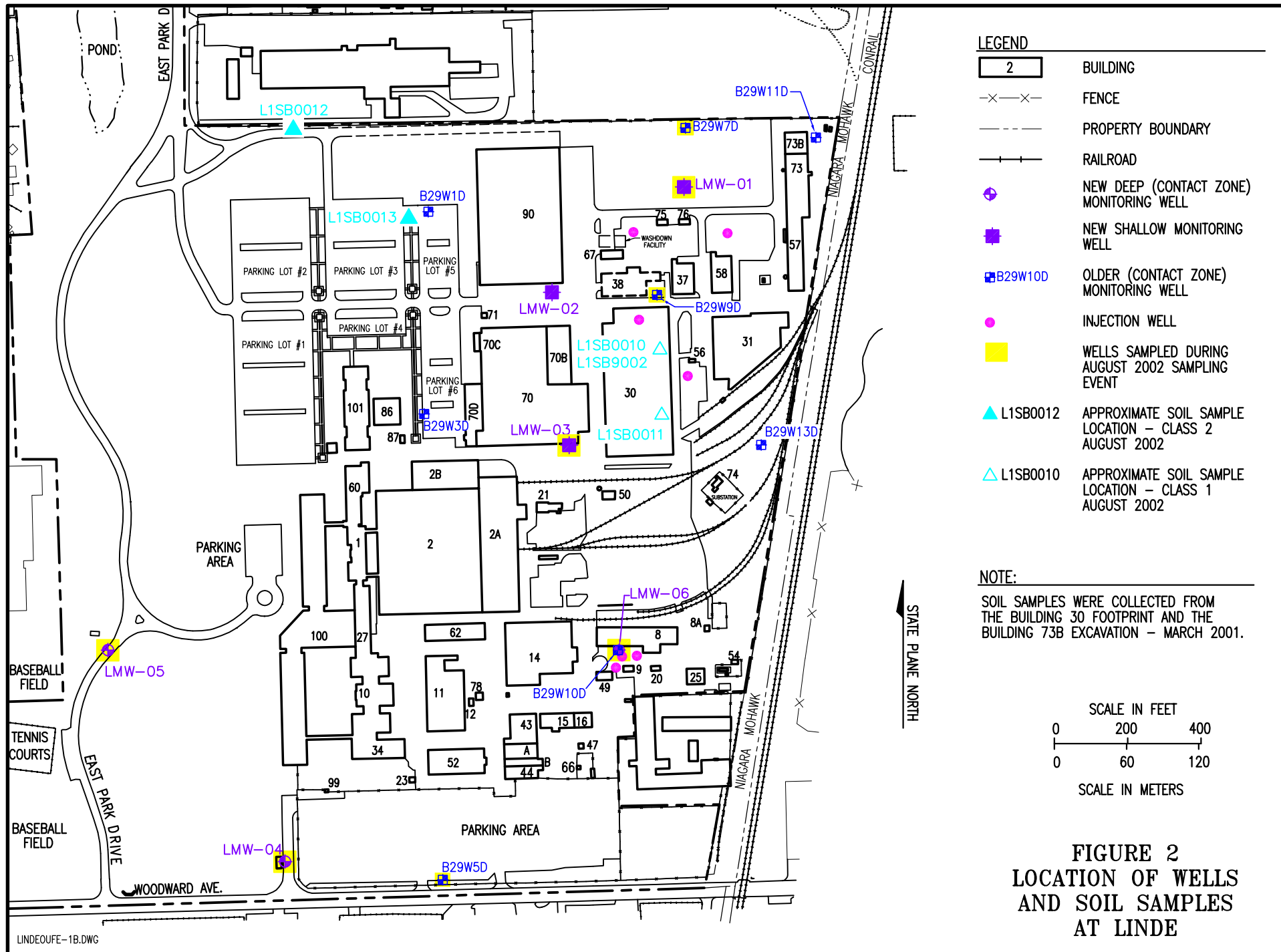
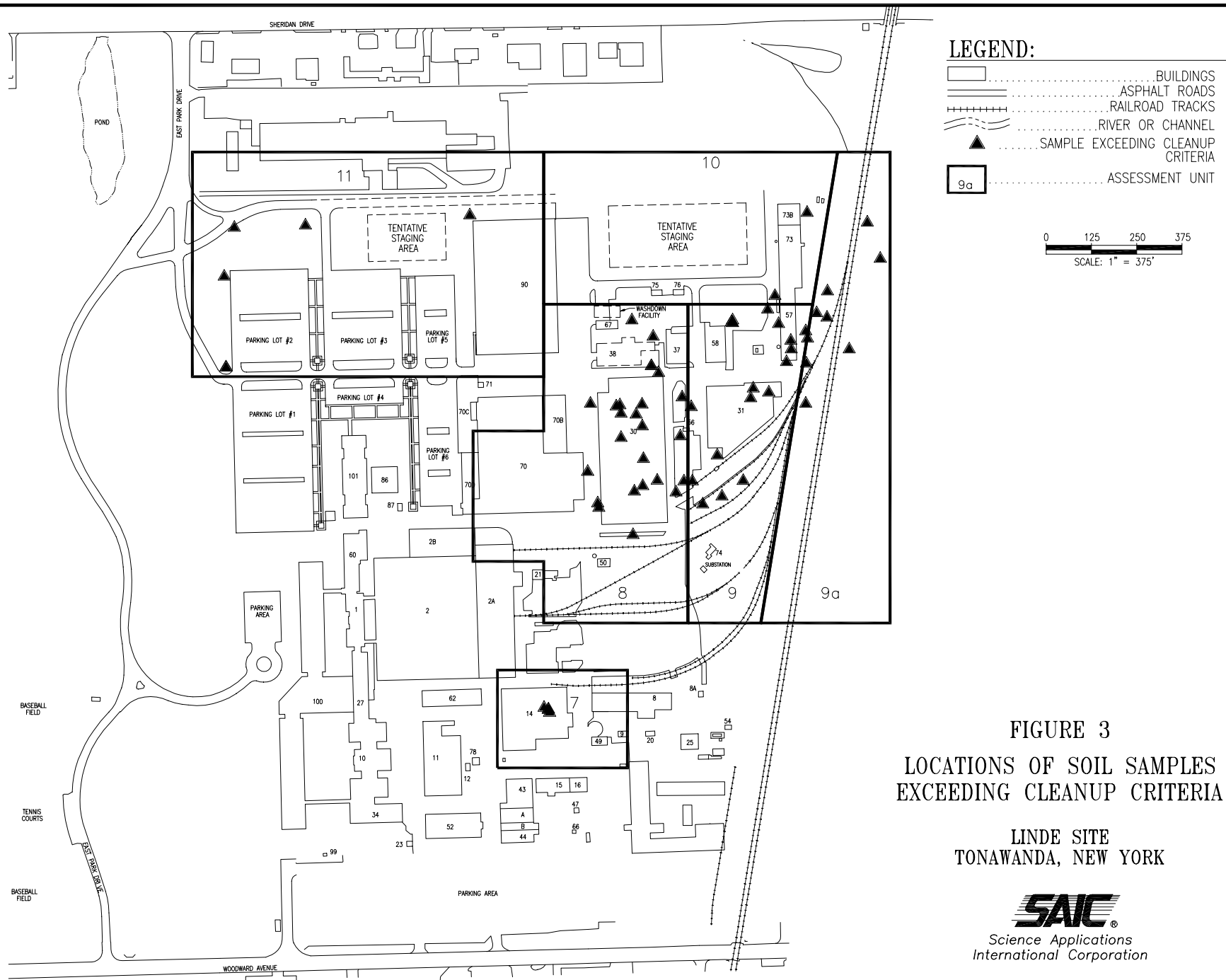


FIGURE 1  
LOCATIONS OF ASHLAND 1, ASHLAND 2,  
SEAWAY, LINDE AND THE TOWN OF TONAWANDA LANDFILL SITES





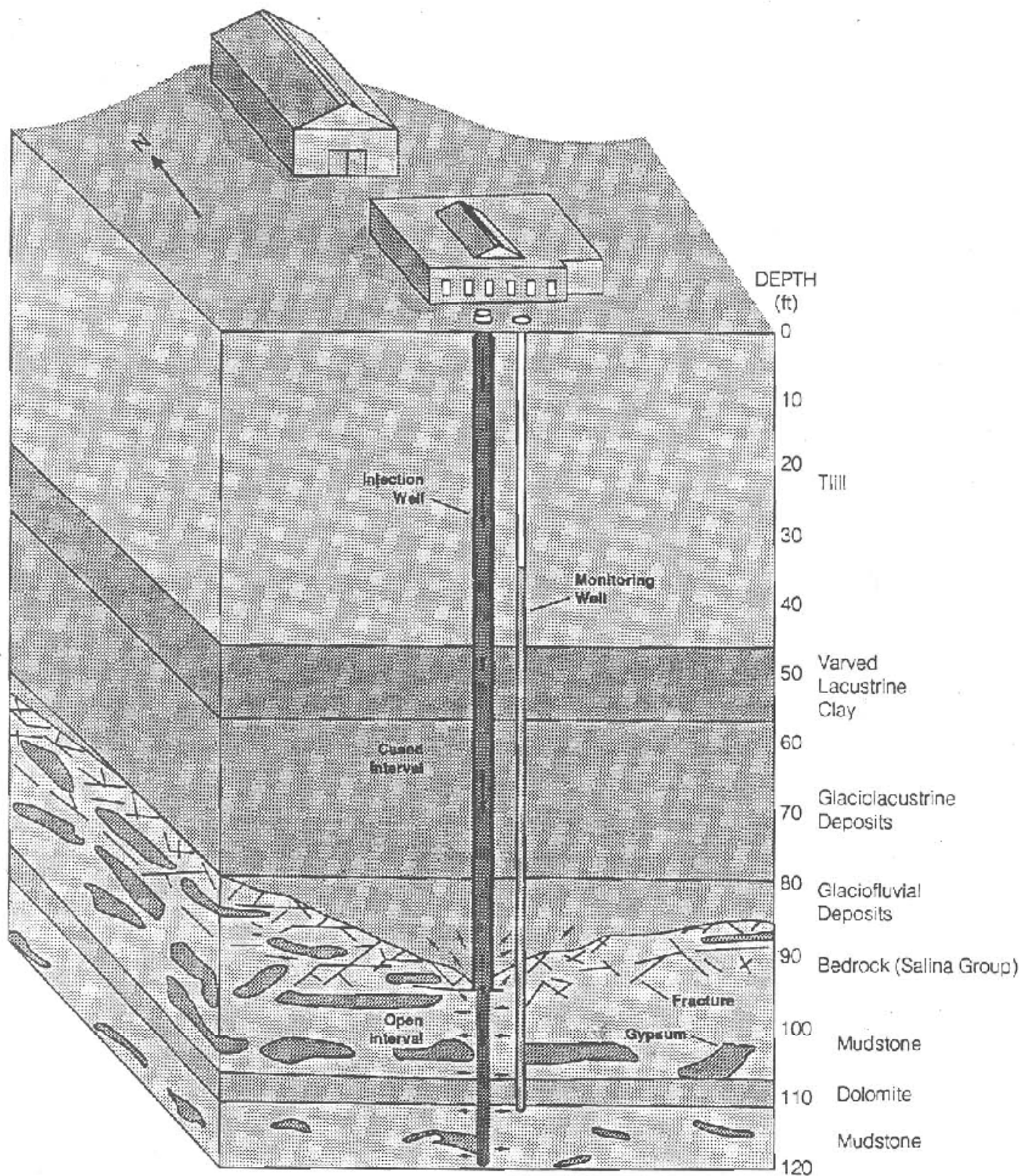


FIGURE 4  
SCHEMATIC DRAWING SHOWING FATE OF INJECTION  
WELL FLUIDS AT LINDE



## **TABLES**

**Table 1. Concentrations of Selected Radionuclides in Groundwater Samples**  
**Collected by Linde Division and Processed by Argonne National Laboratory\* - 1981 Aerospace Report**  
 (Source: Table 6 of Aerospace, 1981)

Sampling Location	Average Concentrations of Radionuclides Dissolved in Solution x 10 <sup>8</sup> µCi/mL						
	Radium-226	Uranium-238**	Uranium-235**	Uranium-234**	Thorium-232	Thorium-230	Thorium-228
Test Well Near Building 38 (former Ceramics Plant)	0.026	0.23	0.01	0.23	0.074	0.017	0.049
Test Well Near Building 8 (Plant No. 1)	0.125	0.078	0.004	0.078	0.003	0.205	0.004
Gas Well Near Building 77	1.68	3.83	0.17	3.83	0.07	0.319	0.07
Well 2 km West of Linde Property	0.0004	Total Uranium <0.03			0.002	0.008	0.002
NRC Limit for Unrestricted Use*** (based on annual average)	3	4000	3000	3000	200	200	700

Sampling Location	Average Concentrations of Radionuclides Suspended in Solution x 10 <sup>8</sup> µCi/mL of Groundwater (pCi/g of Suspended Solid)						
	Radium-226	Uranium-238**	Uranium-235**	Uranium-234**	Thorium-232	Thorium-230	Thorium-228
Test Well Near Building 38 (former Ceramics Plant)	1.40 (0.54)	5.09 (3.25)	0.23 (0.15)	5.09 (3.25)	0.94 (0.50)	1.04 (0.60)	1.20 (0.59)
Test Well Near Building 8 (Plant No. 1)	4.03 (3.08)	625.9 (629.8)	28.16 (28.33)	625.4 (629.8)	0.92 (0.58)	55.78 (52.47)	0.89 (0.55)
Gas Well Near Building 77	1.36 (0.94)	76.28 (52.65)	3.43 (2.37)	76.28 (52.65)	0.07 (0.05)	0.32 (0.22)	0.4 (0.30)
Well 2 km West of Linde Property	0.04 (15.00)	Total Uranium <0.03 (<1.4)			0.00007 (0.01)	0.0002 (0.08)	0.0005 (0.20)
NRC Limit for Unrestricted Use*** (based on annual average)	3000	4000	3000	3000	4000	3000	1000

\* A complete listing of Argonne's results is presented in the Aerospace Report (Aerospace 1981).

\*\* The analysis conducted by Argonne was for total uranium. Concentrations of the uranium isotopes were calculated assuming 1 Ci of natural uranium contains 0.489 Ci of uranium-238, 0.409 Ci of uranium-234, and 0.022 Ci of uranium-235.

\*\*\*Code of Federal Regulations, Title 10, Part 20, Appendix B, Table II, Column 2 (in effect in 1981).

**Table 2. Radionuclide Concentrations in Groundwater Samples Collected  
and Analyzed by Oak Ridge Associated Universities - 1981 Aerospace Report**  
(Source: Table 7 of Aerospace, 1981)

Sampling Location	Concentration of Radionuclides x 10 <sup>8</sup> μCi/mL				
	Radium-226	Uranium-238	Uranium-235	Thorium-232	Thorium-230
Linde Test Well Near Building 38 (near the former Ceramics Plant)	0.031	<59	1	<0.01	0.06
Linde Test Well near Building 8 (near the site of Plant No. 1)	0.016	<64	<0.5	<0.01	0.02
Residential Well 2 km North of Linde	0.091	<49	<0.4	<0.01	
NRC Limit for Unrestricted Use* (based on annual average)	3	4000	3000	200	200

\* Code of Federal Regulations, Title 10, Part 20, Appendix B, Table II, Column 2 (in effect in 1981).

**Table 3. Radionuclide Concentrations in Selected Groundwater Samples from Linde and Vicinity - 1993 RI Report**  
(Source: Table 1-2 from RI Report)

Sample No/Location	Sampled by	Concentration (pCi/L)					
		Ra-226	Th-232	U-234	U-238	U-235	Th-230
W3/City Water <sup>a</sup>	ORAU	0.41	<0.3	NA	<570	10	<0.60
W22/Boreholes*	FBDU	0.6	NA	NA	70	NA	NA
W23/Test Well 1	ORAU	0.31	<0.1	NA	<590	10	0.60
W24 Test Well 2	ORAU	0.16	<0.1	NA	<640	<5.0	0.2

<sup>a</sup> Collected from the Tonawanda city water supply located 2 km (2.4 mi) upstream from the confluence of the Niagara River and Twomile Creek.

\* For this location, each value in the table is the average result based on three borehole samples.

**Table 4. Radium-226 and Uranium-238  
Concentrations in Groundwater - 1981 Aerospace Report**

(Units: concentration x 10<sup>-8</sup> µCi/mL of water)

(Source: Table ES-2, Aerospace, 1981)

Sampling Location	Radium-226		Uranium-238	
	Soluble	Insoluble	Soluble	Insoluble
Two Test Wells Drilled Near Disposal Wells	<0.1*	2.7	0.2**	320**
Old Gas Well on Linde Property	1.7	4	3.8**	76.3**
Industrial Well 2 km West of Linde Property	<0.004	0.2	<0.02**	<0.002**
Residential Well 2 km North of Linde Property	0.09		<53***	
NRC Limits for Unrestricted Use**** (based on annual average)	3	3000	4000	4000

\* The value was less than (<) the detectable limit (in this case, 0.1) of the analytical procedure used. The actual value would range anywhere from 0 to the detectable limit.

\*\* Argonne National Laboratory measured total uranium. The fraction of uranium-238 was calculated assuming the uranium isotopes are in equilibrium.

\*\*\* Analyses of the residential well waters were done by Oak Ridge Associated Universities; all other data presented were based on analyses by Argonne National Laboratory.

\*\*\*\* Code of Federal Regulations, Title 10, Part 20, Appendix B, Table II, Column 2 (in effect in 1981).

**Table 5. Summary of Linde Borehole/Well Data from the 1993 RI Report**

Borehole Number	Ground Elevation (ft MSL <sup>1</sup> )	Screened Interval (ft MSL)		Elevation Of Bottom of Seal (ft MSL)	Total Depth of Borehole (ft bgl <sup>1</sup> )	Depth to Top of Well Screen (ft bgl)	Depth of Bottom of Well Screen (ft bgl)	Elevation of Bottom of Borehole (ft MSL)	Elevation Of Top of Bedrock (ft MSL)	Depth to Bedrock (ft bgl <sup>1</sup> )
B29W01D	600.4	504.5	514.5	521.3	150.3	85.9	95.9	450.1	510.1	90.3
B29W03D	601.2	507.2	517.2	524.5	153.5	84.0	94	447.7	518.9	82.3
B29W05D	599.9	501.0	511.0	516.2	154.2	88.9	98.9	445.7	514.2	85.7
B29W07D	601.9	490.5	500.5	513.9	145.1	101.4	111.4	456.8	505.8	96.1
B29W09D	603.3	499.9	509.9	513.3	149.4	93.4	103.4	453.9	507.8	95.5
B29W10D	600.8	504.2	514.2	516.5	155.4	86.6	96.6	445.4	514.4	86.4
B29W11D	603.5	506.0	516.0	518.7	148.7	87.5	97.5	454.8	507.8	95.7
B29W13D	603.3	502.3	512.3	516.3	152.9	91.0	101	450.4	510.4	92.9
LIWRO-1 (4)	600.8	<u>NA</u>	<u>NA</u>	<u>NA</u>	119	NA	NA	<u>481.8</u>	514.9	85.9
LIWRO-2 (4)	600.8	<u>NA</u>	<u>NA</u>	<u>NA</u>	105	NA	NA	<u>495.8</u>	514.6	86.2
Inj. Well No. 2 at Plant No. 1 ( <u>8-in. diameter</u> )		--	--	--	150.6	72	132	--	--	<u>87.0</u>
Inj. Well No. 3 at Plant No. 1 ( <u>15-in. diameter</u> )		--	--	--	130.5	87.3	open hole	--	--	<u>87.0</u>
Inj. Well Drilled at Ceramics Plant		--	--	--	150	98	open hole; large vein at 115 ft rose water to 30ft bgl	--	--	<u>95.0</u>

**NOTES:**

<sup>1</sup> Data from well logs.

**Key:**

Br = Bedrock

Contact Zone = Contact Zone Aquifer

NA = Not applicable; no well installed.

-- = No survey data is available.

**Table 6. Summary of Hydraulic Conductivity Data from 1993 RI Report**

	Ground Elevation (ft MSL)	Screened Interval (ft MSL)		Screened Interval (ft bgl)		Depth to Bedrock (ft)	Test Interval (ft)		Hydraulic Conductivity (cm/s)	Test Interval (ft into bedrock)	
B29W01D	600.4	504.5	514.5	95.9	85.9	90.3					
							90.1	99.3	<1.1X10 <sup>-5</sup>	0.2	-9
							98.7	107.9	<8.6X10 <sup>-6</sup>	-8.4	-17.6
							110.9	120.1	<8.9X10 <sup>-6</sup>	-20.6	-29.8
							121.3	130.4	<8.9X10 <sup>-6</sup>	-31.0	-40.1
							127.3	135.5	<8.8X10 <sup>-6</sup>	-37.0	-45.2
B29W03D	601.2	507.2	517.2	94	84.0	82.3					
							89.1	98.3	<1.0X10 <sup>-5</sup>	-6.8	-16
							99.1	108.3	<8.9X10 <sup>-6</sup>	-16.8	-26.0
							110.3	119.5	3.1X10 <sup>-5</sup>	-28.0	-37.2
							120	129.5	<7.8X10 <sup>-6</sup>	-37.7	-47.2
							131.5	140.7	<7.4X10 <sup>-6</sup>	-49.2	-58.4
							141.5	150.7	<7.4X10 <sup>-6</sup>	-59.2	-68.4
B29W05D	599.9	501.0	511.0	98.9	88.9	85.7					
							104.2	112.7	<1.4X10 <sup>-5</sup>	-18.5	-27.0
							114.2	122.7	<1.3X10 <sup>-5</sup>	-28.5	-37.0
							125.4	133.9	<1.5X10 <sup>-5</sup>	-39.7	-48.2
							135.2	143.7	<1.6X10 <sup>-5</sup>	-49.5	-58.0
B29W07D	601.9	490.5	500.5	111.4	101.4	96.1					
							101.2	145.0	3.5X10 <sup>-4</sup>	-5.1	-48.9
B29W09D	603.3	499.9	509.9	103.4	93.4	95.5					
							95.5	104.6	2.6X10 <sup>-4</sup>	0	-9.1
							103.7	112.8	<1.0X10 <sup>-5</sup>	-8.2	-17.3
							113.4	122.5	<1.0X10 <sup>-5</sup>	-17.9	-27
							124.6	133.7	<8.9X10 <sup>-6</sup>	-29.1	-38.2
							134.6	143.7	<8.2X10 <sup>-6</sup>	-39.1	-48.2
B29W10D	600.8	504.2	514.2	96.6	86.6	86.4					
							86.5	95.7	<1.1X10 <sup>-5</sup>	-0.1	-9.3
							100.9	110.1	<1.0X10 <sup>-5</sup>	-14.5	-23.7
							107.7	116.9	<1.1X10 <sup>-5</sup>	-21.3	-30.5
							118.9	128.1	<9.8X10 <sup>-6</sup>	-32.5	-41.7
							143.3	152.4	<9.6X10 <sup>-6</sup>	-56.9	-66.0
B29W11D	603.5	506.0	516.0	97.5	87.5	95.7					
							106.3	115.4	<1.2X10 <sup>-5</sup>	-10.6	-19.7
							113.2	122.4	<1.2X10 <sup>-5</sup>	-17.5	-26.7
							127.4	136.5	<1.2X10 <sup>-5</sup>	-31.7	-40.8
							135.4	144.6	<1.9X10 <sup>-5</sup>	-39.7	-48.9
B29W13D	603.3	502.3	512.3	101	91.0	92.9					
							94.3	103.5	2.1X10 <sup>-4</sup>	-1.4	-10.6
							105.5	114.6	1.1X10 <sup>-5</sup>	-12.6	-21.7
							115.4	124.6	<1.2X10 <sup>-5</sup>	-22.5	-31.7
							123.5	132.7	6.8X10 <sup>-5</sup>	-30.6	-39.8
							136.1	145.3	3.8X10 <sup>-5</sup>	-43.2	-52.4

**NOTES:**

<sup>(1)</sup> Data from Table 3-7 of RI report, unless otherwise noted

Values preceded by a < indicate test with no water take: value indicates test detection limits based on apparatus configuration.

Geometric mean does not include values preceded by <.

**Table 7. Summary of 1992 Groundwater Radiological Results for Monitoring Well B29W09D<sup>1</sup> - 1993 RI Report**  
(Source: Tables 4-64, 4-65 and 4-68 of the 1993 RI Report)

Sampling Date		Gross Alpha		Gross Beta		U-234		U-235		U-238		Total Uranium		Th-228		Th-230		Th-232		Ra-226		K-40	
		D <sup>2</sup>	S <sup>3</sup>	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S
May-89		13	<2	290	2	1.3	0.8	<0.1	<0.1	<0.1	0.8					<0.1	0.2			6.1	0.6		
Aug-89		17	- <sup>4</sup>	270	-	0.5	0.2	<0.1	<0.1	0.3	0.2					0.1	<0.2			7.4 (total)			
Oct-89		32 (total)		250 (total)		0.6	0.7	<0.1	<0.2	0.6	0.8					<0.3	<0.6			8 (total)			
Jan-90		<11 (total)		170 (total)		<0.1	0.2	<0.1	<0.1	<0.1	0.3			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8.8 (total)	260 (total)		
Apr-90		<13 (total)		71 (total)		0.2	<0.2	<0.1	<0.2	0.2	<0.2			<0.7	<0.2	<0.4	<0.2	<0.7	<0.2	7.2 (total)	170 (total)		
Aug-90		17 (total)		54 (total)		0.4	0.4	<0.1	0.1	0.5	0.3			<0.1	0.7	0.2	2.8	<0.1	0.7	6.7 (total)	95 (total)		
Oct-90		<9 (total)		68 (total)		0.1	<0.1	0.1	<0.1	0.1	<0.1			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	6.7 (total)	85 (total)		
Jun-92	post-purge (filtered)									2.5 (total)	7.8 ± 0.8 (mg/l)	NA		<2.2 (total)	NA			3.8 ± 1.0 (total)					
	post-purge (unfiltered)									3.1 (total)	9.7 ± 1.0 (mg/l)	NA		<2.0 (total)	NA			1.3 ± 0.6 (total)					
	pre-purge									145 (total)	452.7 ± 45.8 (mg/l)	50.1 (total)		73.1 ± 16 (total)	43.5 (total)			1.6 ± 0.6 (total)					
40 CFR 192, Table 1 to Subpart A maximum concentrations.						Combined U-234 and U-238: 30 pCi/L						Combined Ra-226 and Ra228: 5 pCi/L											

**NOTES:**

<sup>1</sup> All concentrations are given in pCi/L unless otherwise noted.

<sup>2</sup> Dissolved

<sup>3</sup> Suspended

<sup>4</sup> Not detected.

<sup>5</sup> Blank spaces indicate analyses not performed.



**Table 8 - Boring and Monitoring Well Details and Well Development Details - 2001 Investigation**

**Boring and Monitoring Well Details**

<b>Boring/Well Number</b>	<b>Date Of Boring</b>	<b>Total Depth of Boring (ft)</b>	<b>Diameter of Boring (ft)</b>	<b>Depth to Bedrock (ft)</b>	<b>Date Well Completed</b>	<b>Screened Interval (ft)</b>	<b>Well Diameter (ft)</b>	<b>Total Well Depth (ft)</b>	<b>Depth Designation</b>
LMW - 01	1/30/2001	25	0.5	N/A	1/30/2001	5.21-15.23	0.167	15.5	Shallow
LMW - 02	1/31/2001	20	0.5	N/A	1/31/2001	7.75-17.77	0.167	18.04	Shallow
LMW - 03	1/31/2001	25	0.5	N/A	1/31/2001	7.23-17.25	0.167	17.52	Shallow
LMW - 04	2/1/2001	95.1	0.5	82.4	2/1/2001	74.74-94.78	0.167	95.05	Deep
LMW - 05	2/3/2001	84.6	0.5	71.5	2/3/2001	64.29-84.33	0.167	84.6	Deep
LMW - 06	2/5/2001	148.97	0.5	84.8	2/6/2001	88.79-118.85	0.167	148.97*	Deep

\* 30 feet of solid riser extends from bottom of screen to bottom of hole.

**Well Development Details**

<b>Boring/Well Number</b>	<b>Date Developed</b>	<b>Depth to Water (TOC)</b>	<b>Quantity of water developed (gallons)</b>	<b>Readings at completion of development</b>					
				<b>Eh (mV)</b>	<b>Temp (oC)</b>	<b>pH (S.U.)</b>	<b>Cond. (mS/cm)</b>	<b>DO (mg/L)</b>	<b>Turbidity (NTU)</b>
LMW-01	2/4/01, 2/16/01	2	14	-78	8.8	10.36	13.7	1.3	Clear
LMW-02	2/4/2001	17.4	N/A - Dry	N/A	N/A	N/A	N/A	N/A	N/A
LMW-03	2/4/01, 2/16/01	5.22	12	-72	9.8	6.83	3.72	1.47	Clear
LMW-04	2/4/01, 2/15/01	31.3	270	-87	10.7	8.65	3.31	0.79	0
LMW-05	2/20/2001	27.5	80	-246	10.6	8.77	3.64	1.78	26
LMW-06	2/14/2001	33.64	162	-115	13.7	8.63	10.4	0.25	62
B29W01D	2/20/2001	33.22	145	-323	11.2	8.83	4.92	0.42	38
B29W03D	2/20/2001	34.07	160	-193	12.7	11.75	2.94	1.01	35
B29W05D	2/15/2001	33.3	190	-231	9.8	9.15	5.63	0.89	Clear
B29W07D	2/13/2001	35.15	480	-233	10.5	8.94	7.98	1.04	130
B29W09D	2/13/2001	35.25	190	-269	12.4	9.96	16.3	0.39	61
B29W10D	2/14/2001	33.57	450	NM	14.1	9.21	NM	0.91	149
B29W11D	2/19/2001	36.22	145	-290	10.4	8.88	5.44	0.45	2
B29W13D	2/7/2001	36.75	155	-246	10.5	10.42	11.3	0.62	60

**NOTES:**

TOC = Top of casing

NM = Not Measured

Eh = Redox Potential (millivolts)

S.U. = Standard Units (pH units)

DO = Dissolved Oxygen (mg/L)

Cond = Conductivity (milliSiemens/cm)

NTU = Nephelometric Turbidity Units

**Table 9**  
**Well Purging Details**  
**March and June 2001 and August 2002 Sampling Rounds**

Well	Date	Purge Volume (gallons)	Readings at completion of purge, immediately prior to sampling						
			Eh (mV)	Temp (°C)	pH (S.U.)	Cond. (mS/cm)	DO (mg/L)	Turbidity (NTU)	Sampling Depth (fbg)
<b>LMW-01</b>	Mar-01	0.55	-33	3.7	11.02	16.5	3.34	30	10.0
	Jun-01	0.3	41	21.2	9.41	12.5	1.13	153	12.0
	Aug-02	0.8	-118	27.87	8.6	6.3	1.11	45	10.0
<b>LMW-02</b>	Mar-01	1.75	NS	NS	NS	NS	NS	NS	NS
	Jun-02	NS	NS	NS	NS	NS	NS	NS	NS
	Aug-02	4.0	NS	NS	NS	NS	NS	NS	NS
<b>LMW-03</b>	Mar-01	0.35	110	3.4	7.27	3.81	3.12	11	12.0
	Jun-01	0.4	-121	18.2	7.12	4.02	NM	32.2	13.0
	Aug-02	0.8	-67	24.57	7.45	3.83	1.33	190.1	13.0
<b>LMW-04</b>	Mar-01	5	-199	11	7.41	3.57	NM	127	83.0
	Jun-01	1.0	-192	12.9	8.4	3.64	9.84	72	84.0
	Aug-02	5.0	-251	14.25	8.44	3.59	0.13	71.2	83.0
<b>LMW-05</b>	Mar-01	12	-266	11.2	7.78	4.08	NM	999	70.0
	Jun-01	1.0	-292	12.22	8.09	3.97	2.98	999	70.0
	Aug-02	5.0	-252	13.9	8.31	3.53	0	585	70.0
<b>LMW-06</b>	Mar-01	7	-139	13.5	9.09	18.2	NM	226	100.0
	Jun-01	2.2	-188	17.97	12.75	12.4	3.05	154	100.0
	Aug-02	10.0	-186	17.9	11.77	5.69	0.08	47.8	100.0
<b>B29W01D</b>	Mar-01	12	-349	10.4	7.97	5.82	NM	150	91.0
	Jun-01	1.0	-320	14.44	9.02	5.32	2.57	355	91.0
	Aug-02	NS	NS	NS	NS	NS	NS	NS	NS
<b>B29W03D</b>	Mar-01	3.3	-223	9.1	8.04	3.9	0.51	110	92.0
	Jun-01	3.2	-190	16.9	7.62	4.07	1.64	197	92.0
	Aug-02	NS	NS	NS	NS	NS	NS	NS	NS
<b>B29W05D</b>	Mar-01	6	-287	10.7	7.82	8.47	NM	1.9	94.0
	Jun-01	1.5	-253	17.5	8.88	9.9	2.31	440	94.0
	Aug-02	7.5	-304	15.63	11.42	7.65	0	73.8	94.0
<b>B29W07D</b>	Mar-01	2.5	44	9.8	8.42	11.2	NM	127	106.0
	Jun-01	1.1	73	13.3	8.99	11.7	1.43	417	106.0
	Aug-02	14.0	-68	13.15	9.68	10.5	0.22	221	106.0
<b>B29W09D</b>	Mar-01	2.5	-27	11.2	8.99	17.7	9.7	28	98.0
	Jun-01	2.5	-8	14.3	9.14	20.4	1.96	422	102.0
	Aug-02	2.5	5	22.27	9.81	17.8	0.42	57	98.5
<b>B29W10D</b>	Mar-01	17.5	-188	14.3	9.43	8.32	0.35	790	93.0
	Jun-01	1.0	-259	16.3	11.71	7.69	2.46	20.2	93.0
	Aug-02	NS	NS	NS	NS	NS	NS	NS	NS
<b>B29W11D</b>	Mar-01	3.7	-330	5	8.1	5.94	NM	7	90.0
	Jun-01	2.6	-285	20.8	8.48	5.91	1.3	46.6	93.0
	Aug-02	NS	NS	NS	NS	NS	NS	NS	NS
<b>B29W13D</b>	Mar-01	1.4	-267	5.9	10.09	11.3	0.61	17	98.0
	Jun-01	1.0	-16	20.8	9.21	14.4	2.7	284	98.0
	Aug-02	NS	NS	NS	NS	NS	NS	NS	NS

**NOTES:**

fbg = Feet below grade

NS = Not Sampled. LMW-02 not sampled due to low recharge.

NM = Not Measured - probe malfunction

Eh = Redox Potential (millivolts)

Temp = Temperature (°C)

S.U. = Standard Units (pH units)

Cond = Conductivity (milliSiemens/cm)

DO = Dissolved Oxygen (mg/L)

NTU = Nephelometric Turbidity Units

**Table 10 - Sampling Results**  
**Unfiltered and Filtered Samples From Deep Wells**  
**Ra - 226 and Ra - 228**

UNFILTERED	Ra-226						Ra-228					
Standard	NS		NS		NS		NS		NS		NS	
Units	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
WELL	March 2001		June 2001		August 2002		March 2001		June 2001		August 2002	
B29W01D	0.723		0.637		N/A	N/A	1.8	J	1.53		N/A	N/A
B29W03D	1.23		0.854		N/A	N/A	2.07		-1.29	U	N/A	N/A
B29W05D	0.313	U	1.44		0.29	LT	1.01		0.68		1.06	
B29W07D	1.12		1.28		0.28	LT	0.2	J	1.7		0.84	LT
B29W07D (DUP)	0.309	U	1.05		N/A	N/A	0.59	J	1.37		N/A	N/A
B29W09D	0.509		0.51		0.19	Y1	0.71	J	1.35		1.12	
B29W09D (DUP)	0.637		N/A	N/A	N/A	N/A	0.8	J	N/A	N/A	N/A	N/A
B29W10D	2.69		0.35	U	N/A	N/A	-1	J	0.18		N/A	N/A
B29W11D	1.19		1.21		N/A	N/A	0.79	J	0.76		N/A	N/A
B29W13D	0.911		1.11		N/A	N/A	0.02	J	0.51		N/A	N/A
LMW-04	0.925		0.556	U	0.17		0.44	J	0.4		1.3	
LMW-04 (DUP)	N/A	N/A	0.373	U	N/A	N/A	N/A	N/A	-0.04		N/A	N/A
LMW-05	0.879		0.793		0.9	LT	4.5	J	3.6		1.28	
LMW-06	66.4		0.584		0.6	LT	3.6	J	1.99		1.38	
LMW-06 (DUP)	N/A	N/A	N/A	N/A	0.79	LT,Y1	N/A	N/A	N/A	N/A	1.38	

FILTERED	Ra-226						Ra-228					
Standard	NS		NS		NS		NS		NS		NS	
Units	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
WELL	March 2001		June 2001		August 2002		March 2001		June 2001		August 2002	
B29W01D	0.453		0.52		N/A	N/A	0.62		0.25		N/A	N/A
B29W03D	1.4		1		N/A	N/A	1.38		2.14		N/A	N/A
B29W05D	0.533	U	0.55		0.24	LT	1.24		0.41		1.51	
B29W07D	0.426		0.448	U	0.09	U,Y1	0.98		0.39		1.42	
B29W07D (DUP)	0.279	U	0.558		N/A	N/A	0.58	J	0.63		N/A	N/A
B29W09D	1.03	U	0.529		0.3	LT	1.36		0.62		1.1	
B29W09D (DUP)	0.586		N/A	N/A	N/A	N/A	0.46	J	N/A	N/A	N/A	N/A
B29W10D	3.03		0.799		N/A	N/A	0.74	J	0.34		N/A	N/A
B29W11D	0.682		1.21		N/A	N/A	0.74	J	0.7		N/A	N/A
B29W13D	0.699		1.21		N/A	N/A	0.46	J	0.21		N/A	N/A
LMW-04	0.567		1.03		0.17		0.22	J	0.99		0.57	U
LMW-04 (DUP)	N/A	N/A	0.621		N/A	N/A	N/A	N/A	0.47		N/A	N/A
LMW-05	1.34		0.807		0.75	LT	0.93		0.21		0.47	U
LMW-06	1.34		1.01		0.69	LT,Y1	0.37	J	0.41		0.96	LT
LMW-06 (DUP)	N/A	N/A	N/A	N/A	0.57	LT,Y1	N/A	N/A	N/A	N/A	0.75	LT

N/A means not applicable, sample was not collected for the date indicated.

NS means no groundwater standard for this analyte.

Qual = Data qualifier included in report from the laboratory.

U means the result is less than the sample specific minimum detectable concentration (MDC).

LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

J means the results is estimated.

**Table 11 - Sampling Results**  
**Unfiltered and Filtered Samples From Deep Wells**  
**U - 234 and U - 235**

<b>UNFILTERED</b>	<b>U-234</b>						<b>U-235</b>					
<b>Standard</b>	NS		NS		NS		NS		NS		NS	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>		<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
B29W01D	1.14		0.67	LT	N/A	N/A	0.01	U	0.25	LT	N/A	N/A
B29W03D	0.41		0.73	LT	N/A	N/A	0.018	U	0.24	LT	N/A	N/A
B29W05D	0.32	U	0.07	LT	0.46	LT	-0.04	U	0.02	U	0.07	U
B29W07D	0.107		0.4	LT	0.44	LT	0.02	U	0.056	LT	0.13	U
B29W07D (DUP)	0.057	U	0.283	LT	N/A	N/A	0.022	U	-0.003	U	N/A	N/A
B29W09D	0.32		0.74	LT	0.76	LT	0.013	U	0.18		0.08	U
B29W09D (DUP)	0.63		N/A	N/A	N/A	N/A	0.057		N/A	N/A	N/A	N/A
B29W10D	336		10.9		N/A	N/A	17.4		1.12		N/A	N/A
B29W11D	0.3	U	0.153	LT	N/A	N/A	0.03	U	0.016	U	N/A	N/A
B29W13D	0.03	U	0.071	LT	N/A	N/A	0.28	U	0.008	U	N/A	N/A
LMW-04	9.9		2.18		2.96		0.4	U	0.43		0.25	
LMW-04 (DUP)	N/A	N/A	2.52		N/A	N/A	N/A	N/A	0.45	LT	N/A	N/A
LMW-05	7.5		4.5		2.93		0.77		0.77	LT	0.23	
LMW-06	263		6.6		32.7		12.2		0.28		3.52	
LMW-06 (DUP)	N/A	N/A	N/A	N/A	31.6		N/A	N/A	N/A	N/A	5.8	

<b>FILTERED</b>	<b>U-234</b>						<b>U-235</b>					
<b>Standard</b>	NS		NS		NS		NS		NS		NS	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>		<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
B29W01D	0.17	U	0.67	LT	N/A	N/A	0.27		0.29		N/A	N/A
B29W03D	0.33		0.06	U	N/A	N/A	0.005	U	0.06	U	N/A	N/A
B29W05D	0.26	U	0.094	LT	0.31	LT	0.05	U	0.003	U	0.07	U
B29W07D	0.101	U	0.026	U	0.24		0.002	U	0.022		0.13	
B29W07D (DUP)	0.01	U	0.045	LT	N/A	N/A	0.044	U	0.007	U	N/A	N/A
B29W09D	0.35		0.42	LT	0.16		0.018		-0.05	U	0.14	LT
B29W09D (DUP)	0.37		N/A	N/A	N/A	N/A	0.043		N/A	N/A	N/A	N/A
B29W10D	165		1.62		N/A	N/A	8.3		0.13	U	N/A	N/A
B29W11D	0.24	U	0.085		N/A	N/A	-0.05	U	-0.002	U	N/A	N/A
B29W13D	0.25	U	0.123	LT	N/A	N/A	0.05	U	0.022	LT	N/A	N/A
LMW-04	10.7		2.33		2.5		0.4		0.23	U	0.08	U
LMW-04 (DUP)	N/A	N/A	2.35		N/A	N/A	N/A	N/A	0.28		N/A	N/A
LMW-05	6.4		3.5		2.17		0.27		0.19	LT	0.3	LT
LMW-06	166		0.22	U	15.7		7.6		-0.08	U	1.1	
LMW-06 (DUP)	N/A	N/A	N/A	N/A	19		N/A	N/A	N/A	N/A	2.25	

N/A means not applicable, sample was not collected for the date indicated.

NS means no groundwater standard for this analyte.

Qual = Data qualifier included in report from the laboratory.

U means the result is less than the sample specific minimum detectable concentration (MDC).

LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

J means the results is estimated.

**Table 12 - Sampling Results**  
**Unfiltered and Filtered Samples From Deep Wells**  
**U - 238 and Total Uranium**

UNFILTERED	U-238						Total Uranium					
Standard	NS		NS		NS		44		44		44	
Units	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	µg/L	Qual	µg/L	Qual	µg/L	Qual
WELL	March 2001		June 2001		August 2002		March 2001		June 2001		August 2002	
B29W01D	0.55		0.18		N/A	N/A	1.48		0.3		N/A	N/A
B29W03D	0.36		0.15		N/A	N/A	1.23		0.27		N/A	N/A
B29W05D	0.57		0.092	LT	0.12	U	1.43		0.34		0.106	U
B29W07D	0.069	U	0.39	LT	0.05	U	0.21		1.56		0.731	
B29W07D (DUP)	0.087		0.3	LT	N/A	N/A	0.19		1.81		N/A	N/A
B29W09D	0.4		0.39	LT	0.64	LT	2.16		1.28		1.06	
B29W09D (DUP)	0.67		N/A	N/A	N/A	N/A	2.36		N/A	N/A	N/A	N/A
B29W10D	335		12.5		N/A	N/A	765		24.8		N/A	N/A
B29W11D	0.15	U	0.12	LT	N/A	N/A	0.18		0.31		N/A	N/A
B29W13D	0.13	U	0.087	LT	N/A	N/A	0.23		0.53		N/A	N/A
LMW-04	11.2		2.07		2.82		29		6.92		8.53	
LMW-04 (DUP)	N/A	N/A	2.16		N/A	N/A	N/A	N/A	6.23		N/A	N/A
LMW-05	7.4		4.6		2.82		26.6		8.9		9.04	
LMW-06	281		7.4		30.5		837		17.9		98.8	
LMW-06 (DUP)	N/A	N/A	N/A	N/A	34.5		N/A	N/A	N/A	N/A	97.2	

FILTERED	U-238						Total Uranium					
Standard	NS		NS		NS		44		44		44	
Units	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	µg/L	Qual	µg/L	Qual	µg/L	Qual
WELL	March 2001		June 2001		August 2002		March 2001		June 2001		August 2002	
B29W01D	0.27		0.21	U	N/A	N/A	0.27		0.19		N/A	N/A
B29W03D	0.2		0.06	U	N/A	N/A	1.84		0.4		N/A	N/A
B29W05D	0.18	U	0.064	LT	0.09	U	0.52		0.08		0.166	U
B29W07D	0.018	U	0.006		0.1	U	0.07		0.04		0.361	
B29W07D (DUP)	-0.003	U	0.017	U	N/A	N/A	0.09		0.05		N/A	N/A
B29W09D	0.38		0.36		0.21	LT	1.83		0.45		0.63	
B29W09D (DUP)	0.41		N/A	N/A	N/A	N/A	1.92		N/A	N/A	N/A	N/A
B29W10D	167		1.25		N/A	N/A	470		3.63		N/A	N/A
B29W11D	0.49	U	0.113	LT	N/A	N/A	0.28		0.19		N/A	N/A
B29W13D	-0.04	U	0.129	LT	N/A	N/A	0.12		0.16		N/A	N/A
LMW-04	9.6		1.55		2.62		27.3		5.34		8.2	
LMW-04 (DUP)	N/A	N/A	2.44		N/A	N/A	N/A	N/A	6.39		N/A	N/A
LMW-05	5.9		1.93		2.15		18.1		6.73		7.79	
LMW-06	173		0.04	U	15.8		390		0.24		58.8	
LMW-06 (DUP)	N/A	N/A	N/A	N/A	18.3		N/A	N/A	N/A	N/A	62.9	

N/A means not applicable, sample was not collected for the date indicated.

NS means no groundwater standard for this analyte.

Qual = Data qualifier included in report from the laboratory.

U means the result is less than the sample specific minimum detectable concentration (MDC).

LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

J means the results is estimated.

**Table 13 - Sampling Results**  
**Unfiltered and Filtered Samples From Deep Wells**  
**Th - 232 and Th - 230**

UNFILTERED	Th-232						Th-230					
Standard	NS		NS		NS		NS		NS		NS	
Units	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
WELL	March 2001		June 2001		August 2002		March 2001		June 2001		August 2002	
B29W01D	0.38		0.032	U	N/A	N/A	0.63		0.36	LT	N/A	N/A
B29W03D	-0.003	U	-0.015	U	N/A	N/A	0.078	U	0.41	LT	N/A	N/A
B29W05D	0.09	U	0.007	U	0.019	U	0.52		0.098	LT	0.17	LT
B29W07D	-0.003	U	0.14		0.064		0.074	U	0.68	LT	0.43	LT
B29W07D (DUP)	0.034	U	0.174	LT	N/A	N/A	0.27		0.333	LT	N/A	N/A
B29W09D	0.034	U	0.119	LT	0.022	U	0.077	U	0.53	LT	0.22	LT
B29W09D (DUP)	0.003	U	N/A	N/A	N/A	N/A	0.097	U	N/A	N/A	N/A	N/A
B29W10D	0.51		0.019		N/A	N/A	8.1		0.154	LT	N/A	N/A
B29W11D	-0.01	U	0.071		N/A	N/A	0.3		0.49	LT	N/A	N/A
B29W13D	0.03	U	0.125	LT	N/A	N/A	0.03	U	0.41	LT	N/A	N/A
LMW-04	0.06	U	0.014		0.047	U	0.29	U	0.031	LT	0.109	
LMW-04 (DUP)	N/A	N/A	0.007	U	N/A	N/A	N/A	N/A	0.036		N/A	N/A
LMW-05	0.81		0.83		0.15	LT	1.21		1.8		0.29	LT
LMW-06	0.34	U	0.061	U	0.018	U	6.8		0.49	LT	0.18	LT
LMW-06 (DUP)	N/A	N/A	N/A	N/A	0.021	U	N/A	N/A	N/A	N/A	0.16	LT

FILTERED	Th-232						Th-230					
Standard	NS		NS		NS		NS		NS		NS	
Units	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
WELL	March 2001		June 2001		August 2002		March 2001		June 2001		August 2002	
B29W01D	-0.02	U	0.14	U	N/A	N/A	0.22		0.02		N/A	N/A
B29W03D	0.022	U	0.003		N/A	N/A	0.15		0.033	LT	N/A	N/A
B29W05D	-0.02	U	0.0083	LT	0.016	U	0.14		0.069	LT	0.17	LT
B29W07D	-0.004	U	0.005	U	0.076		-0.011	U	0.092	LT	0.12	
B29W07D (DUP)	-0.023	U	-0.009	U	N/A	N/A	0.135		0.05	LT	N/A	N/A
B29W09D	0.009	U	0.007	U	0.056	U	0.077	U	0.039	LT	0.22	LT
B29W09D (DUP)	-0.003	U	N/A	N/A	N/A	N/A	0.146		N/A	N/A	N/A	N/A
B29W10D	-0.013	U	0.004	U	N/A	N/A	0.12	U	0.089	LT	N/A	N/A
B29W11D	0.03	U	0.016		N/A	N/A	0.34	U	0.07	LT	N/A	N/A
B29W13D	-0.04	U	0.003	U	N/A	N/A	0.19	U	0.034	LT	N/A	N/A
LMW-04	-0.07	U	0.006	U	0.025	U	0.14	U	0.018		0.21	LT
LMW-04 (DUP)	N/A	N/A	0.014		N/A	N/A	N/A	N/A	0.03	LT	N/A	N/A
LMW-05	-0.021	U	0.021		0.079		0.12	U	0.026		0.077	
LMW-06	0.08	U	0.0057		0.066	LT	0.76		0.037		0.41	LT
LMW-06 (DUP)	N/A	N/A	N/A	N/A	0.019	U	N/A	N/A	N/A	N/A	0.15	LT

N/A means not applicable, sample was not collected for the date indicated.

NS means no groundwater standard for this analyte.

Qual = Data qualifier included in report from the laboratory.

U means the result is less than the sample specific minimum detectable concentration (MDC).

LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity

J means the results is estimated.

**Table 14 - Sampling Results**  
**Unfiltered and Filtered Samples From Deep Wells**  
**Gross Alpha (Gross  $\alpha$ ) and Gross Beta (Gross  $\beta$ )**

UNFILTERED	Gross $\alpha$ <sup>(1)</sup>						Gross $\beta$					
Standard	NS		NS		NS		NS		NS		NS	
Units	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
WELL	March 2001		June 2001		August 2002		March 2001		June 2001		August 2002	
B29W01D	12.5	U	1.7	U	N/A	N/A	17		13		N/A	N/A
B29W03D	3.9	U	12.2		N/A	N/A	42		50		N/A	N/A
B29W05D	-7.4	U	9		-6	U	25		18		10	U
B29W07D	-1	U	-5	U	1	U	22	U	40		27	
B29W07D (DUP)	8	U	17		N/A	N/A	23	U	28		N/A	N/A
B29W09D	-12	U	53		-10	U	18	U	62		40	
B29W09D (DUP)	8	U	N/A	N/A	N/A	N/A	-4	U	N/A	N/A	N/A	N/A
B29W10D	472		9	U	N/A	N/A	387		25		N/A	N/A
B29W11D	-2	U	-1	U	N/A	N/A	4	U	9	U	N/A	N/A
B29W13D	8	U	9	U	N/A	N/A	17	U	16		N/A	N/A
LMW-04	12.1		7.8		3.2	U	6.4	U	6.1	U	1.3	U
LMW-04 (DUP)	N/A	N/A	2.9	U	N/A	N/A	N/A	N/A	6.1	U	N/A	N/A
LMW-05	28		16.1		3.4	U	37		21		13.3	
LMW-06	416		25		47		201		12	U	42	
LMW-06 (DUP)	N/A	N/A	N/A	N/A	38		N/A	N/A	N/A	N/A	43	

FILTERED	Gross $\alpha$ <sup>(1)</sup>						Gross $\beta$					
Standard	NS		NS		NS		NS		NS		NS	
Units	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
WELL	March 2001		June 2001		August 2002		March 2001		June 2001		August 2002	
B29W01D	3.1	U	4	U	N/A	N/A	50		16.5		N/A	N/A
B29W03D	2.7	U	9.7		N/A	N/A	32.7		41		N/A	N/A
B29W05D	-1.7	U	27		2	U	28		42		25	
B29W07D	-2	U	4	U	-6	U	31	U	25		31	
B29W07D (DUP)	-1	U	1	U	N/A	N/A	26	U	11	U	N/A	N/A
B29W09D	-19	U	37		-21	U	15	U	81		21	U
B29W09D (DUP)	-16	U	N/A	N/A	N/A	N/A	30	U	N/A	N/A	N/A	N/A
B29W10D	224		-4	U	N/A	N/A	130		3	U	N/A	N/A
B29W11D	11	U	3	U	N/A	N/A	21	U	1	U	N/A	N/A
B29W13D	-17	U	7	U	N/A	N/A	24	U	27		N/A	N/A
LMW-04	11.5	U	8	U	-0.5	U	2.1	U	-2.3	U	6.4	U
LMW-04 (DUP)	N/A	N/A	3.8	U	N/A	N/A	N/A	N/A	-0.6	U	N/A	N/A
LMW-05	7.9	U	6.5	U	1.8	U	12.9	U	-1.6	U	3.3	U
LMW-06	222		2	U	29		107		15		28	
LMW-06 (DUP)	N/A	N/A	N/A	N/A	32		N/A	N/A	N/A	N/A	26	

N/A means not applicable, sample was not collected for the date indicated.

NS means no groundwater standard for this analyte.

<sup>(1)</sup> Gross alpha radiation (Gross  $\alpha$ ) reported in this table includes uranium.

Qual = Data qualifier included in report from the laboratory.

U means the result is less than the sample specific minimum detectable concentration (MDC).

LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

J means the results is estimated.

**Table 15 Sampling Results**  
**Unfiltered and Filtered Samples From Shallow Wells**  
**Ra - 226, Ra - 228, U - 235, and U - 238**

**UNFILTERED**

	Ra-226						Ra-228					
<b>Standard</b>	NS		NS		NS		NS		NS		NS	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>		<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
LMW-01	1.32		0.843		0.38	LT	0.74	J	0.78		0.43	U
LMW-03	0.982		0.657		0.209	LT	0.6	J	0.27		0.61	U

**FILTERED**

	Ra-226						Ra-228					
<b>Standard</b>	NS		NS		NS		NS		NS		NS	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>		<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
LMW-01	1.44		0.567		0.27	LT,Y1	1.27		1.15		0.91	LT
LMW-03	2.14		0.92		0.19	LT	0.35	J	0.04		0.5	U

**UNFILTERED**

	U-235						U-238					
<b>Standard</b>	NS		NS		NS		NS		NS		NS	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>		<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
LMW-01	-0.02	U	0.157	LT	1.01		-0.02	U	3.02		5.6	
LMW-03	1.2		0.7	LT	0.78	LT	16.8		14.3		14.5	

**FILTERED**

	U-235						U-238					
<b>Standard</b>	NS		NS		NS		NS		NS		NS	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>		<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
LMW-01	-0.07	U	0.059	LT	0.45	LT	-0.07	U	0.56	LT	5.2	
LMW-03	0.98		1.37		1.33		13.8		14.8		13.5	

N/A means not applicable, sample was not collected for the date indicated.

NS means no groundwater standard for this analyte.

Qual = Data qualifier included in report from the laboratory.

U means the result is less than the sample specific minimum detectable concentration (MDC).

LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

J means the results is estimated.



**Table 16 - Sampling Results**  
**Unfiltered and Filtered Samples From Shallow Wells**  
**U - 234, Total Uranium, Gross Alpha (Gross  $\alpha$ ), and Gross Beta (Gross  $\beta$ )**

**UNFILTERED**

	U-234						Total Uranium					
<b>Standard</b>	NS		NS		NS		44		44		44	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	µg/L	Qual	µg/L	Qual	µg/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>		<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
LMW-01	0.12	U	3.37		6.9		0.08	J	8.8		14.5	
LMW-03	17.7		15.3		16.6		39.2		32.6		37.9	

**FILTERED**

	U-234						Total Uranium					
<b>Standard</b>	NS		NS		NS		44		44		44	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	µg/L	Qual	µg/L	Qual	µg/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>		<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
LMW-01	0.08	U	0.64	LT	7.2		0.04	J	1.73		16	
LMW-03	16.7		14.5		13.2		38.7		36.8		25.9	

**UNFILTERED**

	Gross $\alpha$						Gross $\beta$					
<b>Standard</b>	NS		NS		NS		NS		NS		NS	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>		<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
LMW-01	14	U	4	U	9		14	U	8	U	9	U
LMW-03	15.7		21		9.8		15.4		3.9	U	16.3	

**FILTERED**

	Gross $\alpha$						Gross $\beta$					
<b>Standard</b>	NS		NS		NS		NS		NS		NS	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>		<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
LMW-01	24	U	24		1.1	U	30	U	44		0.1	U
LMW-03	15.7		26		6.2		16.5		11.2		10.6	

NS means no groundwater standard for this analyte.

Qual = Data qualifier included in report from the laboratory.

U means the result is less than the sample specific minimum detectable concentration (MDC).

LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

J means the results is estimated.

**Table 17 - Sampling Results**  
**Unfiltered and Filtered Samples From Shallow Wells**  
**Th - 230 and Th - 232**

**UNFILTERED**

	<b>Th-230</b>					
<b>Standard</b>	NS		NS		NS	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
LMW-01	0.32		0.045	LT	0.44	LT
LMW-03	0.13	U	0.06	LT	0.15	

**FILTERED**

	<b>Th-230</b>					
<b>Standard</b>	NS		NS		NS	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
LMW-01	0.2	U	0.058	LT	0.13	LT
LMW-03	0.25		0.032	LT	0.12	

**UNFILTERED**

	<b>Th-232</b>					
<b>Standard</b>	NS		NS		NS	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
LMW-01	0.13	U	0.005	U	0.089	
LMW-03	-0.01	U	0.012		-0.035	U

**FILTERED**

	<b>Th-232</b>					
<b>Standard</b>	NS		NS		NS	
<b>Units</b>	pCi/L	Qual	pCi/L	Qual	pCi/L	Qual
<b>WELL</b>	<b>March 2001</b>		<b>June 2001</b>		<b>August 2002</b>	
LMW-01	-0.06	U	0.005	U	0.002	U
LMW-03	0.09	U	-0.003	U	0.009	U

NS means no groundwater standard for this analyte.

Qual = Data qualifier included in report from the laboratory.

U means the result is less than the sample specific minimum detectable concentration (MDC).

LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

J means the results is estimated.

**Table 18 - Sampling Results**  
**Unfiltered Samples From Deep Wells**  
**Metals Page 1 of 5**

		B29W01D				B29W03D				B29W05D					
	Std (1)	Mar-01		Jun-01		Mar-01		Jun-01		Mar-01		Jun-01		Aug-02	
UNITS	mg/L	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Aluminum	NS	3.1		0.21		0.55		0.33		0.24	B	0.015	U	0.062	B
Antimony	NS	0.0024	U	0.0041	U	0.0024	U	0.0023	B	0.0036	U	0.0041	U	0.0029	U
Arsenic	0.05	0.0015	U	0.003	U	0.0015	U	0.0038	B	0.0022	U	0.003	B	0.0019	B
Barium	1	0.057		0.075		0.023		0.013		0.017	B	0.014	B	0.018	
Beryllium	NS	0.001	B	0.00015	U	0.00044	B	0.000074	U	0.0012	B	0.0014	B	0.00035	B
Boron	NS	1.2		1		20		20		5.3		4.6		4.9	
Cadmium	0.01	0.0002	U	0.00018	B	0.00028	B	0.00023	B	0.0003	U	0.00017	U	0.00014	U
Calcium	NS	530		450		580		550		650		660		630	
Chromium	0.05	0.0096	B	0.0019	B	0.0035	B	0.0025	B	0.002	B	0.00041	U	0.00032	U
Cobalt	NS	0.0029	B	0.0013	B	0.00089	B	0.00084	B	0.0024	B	0.0028	B	0.0031	B
Copper	NS	0.0049	B	0.00053	U	0.0066	B	0.0018	B	0.0013	B	0.00053	U	0.0003	U
Iron	NS	7.2		0.35		1.1		0.97		2.6		0.03	B	0.011	B
Lead	0.05	0.0049		0.0021	U	0.0013	U	0.0021	U	0.00098	U	0.0021	U	0.0031	U
Magnesium	NS	110		100		170		160		150		140		110	
Manganese	NS	0.19		0.04		0.041		0.038		0.026		0.017	B	0.0088	B
Mercury	0.002	1.60E-05	U	0.000033	U	1.60E-05	U	0.000033	U	1.60E-05	U	0.000033	U	0.000011	U
Molybdenum	0.1	0.0045	U	0.0075	U	0.0045	U	0.0038	U	0.0068	U	0.0075	U	0.0032	U
Nickel	NS	0.011	B	0.00098	B	0.0038	B	0.002	B	0.0018	B	0.0006	U	0.0007	B
Potassium	NS	13		23		50		54		32		45		28	
Selenium	0.01	0.0025	U	0.0038	U	0.0025	U	0.0019	U	0.0037	U	0.0038	U	0.0036	U
Silver	0.05	0.00048	B	0.0011	U	0.00062	B	0.0013	B	0.00072	U	0.0028	B	0.00042	U
Sodium	NS	580		600		200		190		740		720		860	
Thallium	NS	0.0028	U	0.0036	U	0.0028	U	0.0077		0.0042	U	0.008	B	0.0041	U
Vanadium	NS	0.0064	B	0.00075	U	0.0011	B	0.00038	U	0.00057	U	0.00075	U	0.00032	U
Zinc	NS	0.13		0.022		0.057		0.031		0.013	B	0.014	B	0.0027	B

(1) Std = Groundwater Standard, 40 CFR Part 192

NS means no groundwater standard for this analyte.

Qual = Data qualifier included in report from the laboratory.

U means the result is less than the sample specific minimum detectable concentration (MDC).

LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

**Table 18 - Sampling Results**  
**Unfiltered Samples From Deep Wells**  
**Metals Page 2 of 5**

UNITS	Std (1) mg/L	B29W07D						B29W07D (DUP)			
		Mar-01		Jun-01		Aug-02		Mar-01		Jun-01	
		mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Aluminum	NS	0.14	B	1.9		1.5		0.083	B	1.2	
Antimony	NS	0.0048	U	0.0041	U	0.0029	U	0.006	U	0.0041	U
Arsenic	0.05	0.0029	U	0.0072	B	0.0039	B	0.0037	U	0.003	U
Barium	1	0.018	B	0.053		0.03		0.023	B	0.056	
Beryllium	NS	0.00058	B	0.0023		0.00064	B	0.00078	B	0.0011	B
Boron	NS	4.1		3.9		4		4.2		3.7	
Cadmium	0.01	0.0004	U	0.0012	B	0.0021		0.0005	U	0.00017	U
Calcium	NS	550		460		520		550		430	
Chromium	0.05	0.0017	B	0.0037	B	0.0038	B	0.00085	U	0.0011	B
Cobalt	NS	0.0025	B	0.0024	B	0.0029	B	0.0021	B	0.0027	B
Copper	NS	0.0048	B	0.047		0.02		0.0037	B	0.024	
Iron	NS	0.39		1.9		1.3		0.49		1.4	
Lead	0.05	0.0013	U	0.016		0.0075		0.0016	U	0.0053	B
Magnesium	NS	150		140		140		150		120	
Manganese	NS	0.039		0.43		0.16		0.037		0.22	
Mercury	0.002	1.60E-05	U	3.30E-05	U	0.000019	B	1.60E-05	U	3.30E-05	U
Molybdenum	0.1	0.045		0.029		0.033		0.048		0.033	
Nickel	NS	0.0022	B	0.019	B	0.011		0.0018	B	0.011	B
Potassium	NS	41		65		34		40		58	
Selenium	0.01	0.0022	U	0.0038	U	0.0036	U	0.0062	U	0.0038	U
Silver	0.05	0.0013	B	0.0013	B	0.00063	B	0.0012	B	0.0011	U
Sodium	NS	1800		1600		1900		1800		1500	
Thallium	NS	0.0056	U	0.0097		0.0051		0.007	U	0.0036	U
Vanadium	NS	0.00077	U	0.00076	B	0.0021	B	0.00096	U	0.00086	B
Zinc	NS	0.18		0.19		0.11		0.18		0.099	

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LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

**Table 18 - Sampling Results**  
**Unfiltered Samples From Deep Wells**  
**Metals Page 3 of 5**

		B29W09D						B29W09D (DUP)		B29W10D			
	Std (1)	Mar-01		Jun-01		Aug-02		Mar-01		Mar-01		Jun-01	
UNITS	mg/L	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Aluminum	NS	0.039	U	0.2	B	0.029	B	0.039	U	4.4		0.015	B
Antimony	NS	0.012	U	0.01	U	0.0029	U	0.012	U	0.0036	U	0.0021	U
Arsenic	0.05	0.0073	U	0.0084	B	0.0035	B	0.0073	U	0.036		0.021	U
Barium	1	0.0017	B	0.01	U	0.019		0.0012	B	0.091		0.033	
Beryllium	NS	0.00053	U	0.0017	B	0.00047	B	0.00053	U	0.00056	B	7.40E-05	U
Boron	NS	0.13	B	0.1	B	0.071	B	0.11	B	0.22		0.15	
Cadmium	0.01	0.001	U	0.00042	U	0.00014	U	0.001	U	0.0077		8.40E-05	U
Calcium	NS	440		450		430		450		680		420	
Chromium	0.05	0.0017	U	0.0023	B	0.00035	B	0.0017	U	0.096		0.00091	B
Cobalt	NS	0.0024	B	0.0075	B	0.0036	B	0.0048	B	0.0042	B	0.00037	U
Copper	NS	0.0022	B	0.0013	U	0.00081	B	0.0017	U	0.38		0.0034	B
Iron	NS	0.17	B	0.87		0.064	B	0.14	B	6.7		0.057	B
Lead	0.05	0.0033		0.0053	U	0.0015	U	0.0033	U	0.02		0.0011	U
Magnesium	NS	67		70		53		69		52		11	
Manganese	NS	0.0099	B	0.07		0.013		0.0099	B	0.17		0.004	B
Mercury	0.002	0.000016	U	3.30E-05	U	0.000011	U	1.60E-05	U	0.013		3.30E-05	U
Molybdenum	0.1	0.43		0.42		0.33		0.44		0.25		0.22	
Nickel	NS	0.003	U	0.0015	U	0.00099	B	0.003	U	0.012	B	0.00083	B
Potassium	NS	45		81		41		46		16		23	
Selenium	0.01	0.012	U	0.0095	U	0.0036	U	0.012	U	0.0037	U	0.0019	U
Silver	0.05	0.0024	U	0.0029	U	0.00042	U	0.0024	U	0.001	B	0.00057	U
Sodium	NS	3900		4200		3900		4000		1100		810	
Thallium	NS	0.014	U	0.012	B	0.0041	U	0.014	U	0.0042	U	0.0038	B
Vanadium	NS	0.0019	U	0.0019	U	0.00032	U	0.0019	U	0.0093	B	0.00038	U
Zinc	NS	0.25		0.071		0.0059	B	0.18	B	0.49		0.005	B

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LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

**Table 18 - Sampling Results**  
**Unfiltered Samples From Deep Wells**  
**Metals Page 4 of 5**

		B29W11D				B29W13D				LMW-04						LMW-04 (DUP)	
	Std (1)	Mar-01		Jun-01		Mar-01		Jun-01		Mar-01		Jun-01		Aug-02		Jun-01	
UNITS	mg/L	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Aluminum	NS	0.0077	U	0.049	B	0.019	U	0.26		0.0077	U	0.0076	U	0.13		0.023	B
Antimony	NS	0.0024	U	0.0021	U	0.006	U	0.0041	U	0.0029	B	0.0031	B	0.0029	U	0.0021	U
Arsenic	0.05	0.0015	U	0.0034	B	0.0037	U	0.0031	B	0.0021	B	0.003	B	0.007		0.0017	B
Barium	1	0.0048	B	0.0079	B	0.038	B	0.028		0.022	B	0.0062	B	0.017		0.005	B
Beryllium	NS	0.00011	U	0.0014		0.00027	U	0.0014	B	0.0005	B	0.00014	B	0.00073	B	0.00016	B
Boron	NS	1.4		1.6		0.4		0.34		0.84		0.64		0.78		0.77	
Cadmium	0.01	0.0002	U	8.40E-05	U	0.0005	U	0.00017	U	0.0002	U	0.00035	B	0.00014	U	8.40E-05	U
Calcium	NS	440		530		420		470		490		450		470		470	
Chromium	0.05	0.00063	B	0.00062	B	0.00085	U	0.00041	U	0.0021	B	0.00067	B	0.0008	B	0.0023	B
Cobalt	NS	0.0004	U	0.0009	B	0.0027	B	0.0037	B	0.0004	U	0.00044	B	0.00053	U	0.00037	U
Copper	NS	0.00088	B	0.00027	U	0.00084	U	0.00053	U	0.001	B	0.00027	U	0.0003	U	0.00027	U
Iron	NS	0.091	B	0.43		0.19	B	0.59		8.1		0.06	B	0.29		0.28	
Lead	0.05	0.00098	U	0.0021	U	0.0016	U	0.0021	U	0.00098	U	0.0011	U	0.0031	U	0.0011	U
Magnesium	NS	120		160		63		55		160		140		160		150	
Manganese	NS	0.022		0.07		0.017	B	0.037		0.039		0.016		0.041		0.02	
Mercury	0.002	1.60E-05	U	3.30E-05	U	1.60E-05	U	3.30E-05	U	1.60E-05	U	3.30E-05	U	1.10E-05	U	3.30E-05	U
Molybdenum	0.1	0.0045	U	0.0038	U	0.011	U	0.012	B	0.021		0.0041		0.0042	B	0.0072	B
Nickel	NS	0.00068	B	0.0036	B	0.0015	U	0.0039	B	0.0014	B	0.00096	B	0.00052	U	0.0003	U
Potassium	NS	12		20		32		53		6.5		9.2		5.1		9.2	
Selenium	0.01	0.0025	U	0.0019	U	0.0062	U	0.0038	U	0.0025	U	0.0019	U	0.0036	U	0.0019	U
Silver	0.05	0.00048	U	0.00057	U	0.0012	U	0.0015	B	0.00063	B	0.00057	U	0.00042	U	0.00057	U
Sodium	NS	540		590		2200		1900		230		230		230		230	
Thallium	NS	0.0028	U	0.0035	B	0.007	U	0.0079	B	0.0028	U	0.0038	B	0.0041	U	0.0018	U
Vanadium	NS	0.00038	U	0.00038	U	0.00096	U	0.00075	U	0.00038	U	0.00038	U	0.00032	U	0.00038	U
Zinc	NS	0.011	B	0.018		0.012	B	0.018	B	0.0016	B	0.0012	B	0.0082	B	0.0028	B

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Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

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**Table 18 - Sampling Results**  
**Unfiltered Samples From Deep Wells**  
**Metals Page 5 of 5**

		LMW-05						LMW-06						LMW-06 (DUP)	
	Std (1)	Mar-01		Jun-01		Aug-02		Mar-01		Jun-01		Aug-02		Aug-02	
UNITS	mg/L	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Aluminum	NS	0.0077	U	0.0076	U	6.5		0.015	U	0.015	U	0.21		0.22	
Antimony	NS	0.0024	U	0.0021	U	0.0029	U	0.0048	U	0.0041	U	0.0029	U	0.0029	U
Arsenic	0.05	0.0015	U	0.0017	B	0.0047	B	0.012	B	0.003	U	0.015		0.013	
Barium	1	0.019	B	0.013		0.056		0.076		0.43		0.073		0.073	
Beryllium	NS	0.00055	B	0.00026	B	0.00034	B	0.0009	B	0.00036	B	0.00038	B	0.00075	B
Boron	NS	0.96		0.98		0.9		0.74		0.51		0.98		1	
Cadmium	0.01	0.0002	U	8.40E-05	U	0.00014	U	0.0004	U	0.00017	U	0.00014	U	0.00014	U
Calcium	NS	570		490		610		560		700		340		320	
Chromium	0.05	0.00034	U	0.00021	U	0.0098		0.0036	B	0.00074	B	0.0015	B	0.0016	B
Cobalt	NS	0.0004	U	0.00037	U	0.0046	B	0.00079	U	0.00073	U	0.0012	B	0.0007	B
Copper	NS	0.00034	U	0.00027	U	0.0077		0.00082	B	0.00053	U	0.00054	B	0.0012	B
Iron	NS	0.038	B	0.047	B	9.1		0.44		0.074	B	0.28		0.27	
Lead	0.05	0.0013	U	0.0021	U	0.0063		0.0013	U	0.0021	U	0.0015	U	0.0015	U
Magnesium	NS	160		150		220		46		0.33	B	27		26	
Manganese	NS	0.0098	B	0.011		0.45		0.032		8.80E-05	U	0.011		0.012	
Mercury	0.002	1.60E-05	U	3.30E-05	U	0.000011	U	0.00028		3.30E-05	U	2.50E-05	B	1.90E-05	B
Molybdenum	0.1	0.0078	B	0.0038	U	0.0032	U	0.37		0.15		0.27		0.27	
Nickel	NS	0.0006	U	0.0003	U	0.0099	B	0.0035	B	0.0006	U	0.0011	B	0.0064	B
Potassium	NS	7.1		9.9		6.9		23		34		17		17	
Selenium	0.01	0.0025	U	0.0019	U	0.0036	U	0.005	U	0.0038	U	0.0036	U	0.0036	U
Silver	0.05	0.00048	U	0.00058	B	0.00042	U	0.0012	U	0.0011	U	0.00067	B	0.00042	U
Sodium	NS	260		260		250		1300		920		980		990	
Thallium	NS	0.0028	U	0.0048	B	0.0041	U	0.0056	U	0.0036	U	0.0048	B	0.0042	B
Vanadium	NS	0.00038	U	0.00038	U	0.013		0.0022	B	0.0012	B	0.0015	B	0.0011	B
Zinc	NS	0.0043	B	0.0025	B	0.062		0.013	B	0.0021	B	0.0074	B	0.0034	B

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B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

**Table 19 - Sampling Results**  
**Filtered Samples From Deep Wells**  
**Metals Page 1 of 5**

		B29W01D				B29W03D				B29W05D					
	Std (1)	Mar-01		Jun-01		Mar-01		Jun-01		Mar-01		Jun-01		Aug-02	
UNITS	mg/L	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Aluminum	NS	0.0077	U	0.015	U	0.0077	U	0.0076	U	0.012	U	0.015	U	0.0065	U
Antimony	NS	0.0035	B	0.0041	U	0.0024	U	0.0021	U	0.0036	U	0.0041	U	0.0036	B
Arsenic	0.05	0.0023	B	0.003	U	0.0015	U	0.0015	U	0.0022	U	0.003	B	0.0045	B
Barium	1	0.07		0.052		0.05		0.034		0.026	B	0.027		0.014	
Beryllium	NS	0.00087	B	0.00015	U	0.00048	B	7.40E-05	U	0.0012	B	0.0017	B	0.00036	B
Boron	NS	1.2		0.97		20		19		5.7		9.1		4.9	
Cadmium	0.01	0.0002	U	0.00017	U	0.0002	U	8.40E-05	U	0.0003	U	0.00017	U	0.00014	U
Calcium	NS	520		490		600		550		650		660		630	
Chromium	0.05	0.0032	B	0.00041	U	0.00034	U	0.00021	U	0.0013	B	0.00041	U	0.00032	U
Cobalt	NS	0.0012	B	0.002	B	0.0004	U	0.00037	U	0.0022	B	0.004	B	0.0032	B
Copper	NS	0.0017	B	0.00053	U	0.00034	U	0.00027	U	0.001	B	0.00053	B	0.0003	U
Iron	NS	11		0.086	B	0.25		0.4		8.3		0.02	B	0.0072	U
Lead	0.05	0.00098	U	0.0021	U	0.0013	U	0.0021	U	0.00098	U	0.0021	U	0.0031	U
Magnesium	NS	110		98		170		160		150		210		98	
Manganese	NS	0.07		0.029		0.018		0.018		0.037		0.049		0.00036	B
Mercury	0.002	1.60E-05	U	3.30E-05	U	1.60E-05	U	3.30E-05	U	1.60E-05	U	3.30E-05	U	0.000011	U
Molybdenum	0.1	0.0045	U	0.0075	U	0.0045	U	0.0038	U	0.0081	B	0.0075	U	0.0032	U
Nickel	NS	0.0028	B	0.00088	B	0.0006	U	0.0003	U	0.0019	B	0.0006	U	0.0015	B
Potassium	NS	15		27		49		53		33		60		29	
Selenium	0.01	0.0025	U	0.0038	U	0.0025	U	0.0019	U	0.0037	U	0.0038	U	0.0036	U
Silver	0.05	0.001	U	0.0011	U	0.00048	U	0.00057		0.00072	U	0.0011	U	0.0011	B
Sodium	NS	590		610		190		180		760		990		920	
Thallium	NS	0.0028	U	0.0099	B	0.0028	U	0.0031	B	0.0042	U	0.0053	B	0.0041	U
Vanadium	NS	0.00067	B	0.00075	U	0.00038	U	0.00038	U	0.00057	U	0.00075	U	0.00042	B
Zinc	NS	0.0026	B	0.0094	B	0.0032	B	0.00031	U	0.0021	B	0.0083	B	0.0031	B

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**Table 19 - Sampling Results**  
**Filtered Samples From Deep Wells**  
**Metals Page 2 of 5**

		B29W07D						B29W07D (DUP)			
	Std (1)	Mar-01		Jun-01		Aug-02		Mar-01		Jun-01	
UNITS	mg/L	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Aluminum	NS	0.019	B	0.015	U	0.0065	U	0.019	U	0.015	U
Antimony	NS	0.006	U	0.0041	U	0.0029	U	0.006	U	0.0041	U
Arsenic	0.05	0.0037	U	0.003	U	0.0027	B	0.0037	U	0.0034	B
Barium	1	0.03	B	0.04		0.014		0.027	B	0.043	
Beryllium	NS	0.0008	B	0.0019	B	0.00053	B	0.00078	B	0.00096	
Boron	NS	4.7		3.1		4.1		4.6		3.2	
Cadmium	0.01	0.0005	U	0.00017	U	0.00014	U	0.0005	U	0.00017	U
Calcium	NS	550		400		490		560		430	
Chromium	0.05	0.00085	U	0.00041	U	0.00032	U	0.00085	U	0.00041	U
Cobalt	NS	0.0022	B	0.0015	B	0.0019	B	0.0019	B	0.0025	B
Copper	NS	0.00084	U	0.00053	U	0.0003	U	0.00084	U	0.00053	U
Iron	NS	0.12	B	0.012	U	0.0072	U	0.11	B	0.012	U
Lead	0.05	0.0016	U	0.0021	U	0.0015	U	0.0016	U	0.0021	U
Magnesium	NS	150		120		130		150		120	
Manganese	NS	0.059		0.017	B	0.026		0.051		0.018	B
Mercury	0.002	1.60E-05	U	3.30E-05	U	1.10E-05	U	1.60E-05	U	3.30E-05	U
Molybdenum	0.1	0.046		0.031		0.036		0.053		0.032	
Nickel	NS	0.0015	U	0.0006	U	0.00052	U	0.0017	B	0.017	B
Potassium	NS	42		60		34		42		58	
Selenium	0.01	0.0062	U	0.0038	U	0.0036	U	0.0062	U	0.0038	U
Silver	0.05	0.0012	U	0.0011	U	0.00071	B	0.0013	U	0.0011	U
Sodium	NS	1700		1500		1900		1700		1500	
Thallium	NS	0.007	U	0.0065	B	0.0052		0.007	U	0.0049	B
Vanadium	NS	0.00096	U	0.00076	B	0.00032	U	0.00096	U	0.00075	U
Zinc	NS	0.15		0.01	B	0.0081	B	0.11		0.015	B

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**Table 19 - Sampling Results**  
**Filtered Samples From Deep Wells**  
**Metals Page 3 of 5**

		B29W09D						B29W09D (DUP)		B29W10D			
	Std (1)	Mar-01		Jun-01		Aug-02		Mar-01		Mar-01		Jun-01	
UNITS	mg/L	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Aluminum	NS	0.039	U	0.038	U	0.0065	U	0.039	U	0.012	U	0.0076	U
Antimony	NS	0.012	U	0.01	U	0.0029	U	0.012	U	0.0036	U	0.0021	U
Arsenic	0.05	0.0073	U	0.0074	U	0.0023	B	0.0073	U	0.023		0.025	
Barium	1	0.0088	B	0.031	B	0.01		0.0047	B	0.048		0.035	
Beryllium	NS	0.00053	U	0.0017	B	0.00042	B	0.00053	U	0.00038	B	0.00099	B
Boron	NS	0.099	B	0.07	B	0.072	B	0.13	B	0.21		0.15	
Cadmium	0.01	0.001	U	0.00055	B	0.00014	U	0.001	U	0.0003	U	8.40E-05	U
Calcium	NS	450		420		420		450		630		470	
Chromium	0.05	0.0017	U	0.001	U	0.00032	U	0.0017	U	0.0008	B	0.00021	U
Cobalt	NS	0.0054	B	0.0054	B	0.0038	B	0.0056	B	0.00059	U	0.00037	U
Copper	NS	0.0017	U	0.0013	U	0.0003	U	0.0026	B	0.00065	B	0.00027	U
Iron	NS	0.2	B	0.15	B	0.0072	U	0.19	B	0.03	B	0.0061	U
Lead	0.05	0.0033	U	0.0053	U	0.0015	U	0.0033	U	0.00098	U	0.0011	U
Magnesium	NS	66		55		48		68		38		4.1	
Manganese	NS	0.009	B	0.02	B	0.00076	B	0.01	B	0.016		0.000044	U
Mercury	0.002	1.60E-05	U	3.30E-05	U	1.10E-05	U	1.60E-05	U	1.60E-05	U	3.30E-05	U
Molybdenum	0.1	0.42		0.42		0.34		0.45		0.24		0.2	
Nickel	NS	0.003	U	0.0015	U	0.00052	U	0.003	U	0.0009	U	0.00078	B
Potassium	NS	46		79		41		44		14		24	
Selenium	0.01	0.012	U	0.0095	U	0.0036	U	0.012	U	0.0037	U	0.0023	B
Silver	0.05	0.0028	U	0.0029	U	0.00063	B	0.0024	U	0.0008	B	0.00057	U
Sodium	NS	3900		4000		3900		3900		1100		820	
Thallium	NS	0.014	U	0.02	B	0.0041	U	0.014	U	0.0042	U	0.0027	B
Vanadium	NS	0.0019	U	0.0019	U	0.00032	U	0.0019	U	0.00057	U	0.00049	B
Zinc	NS	0.017	B	0.0043	B	0.0084	B	0.028	B	0.0042	B	0.0033	B

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U means the result is less than the sample specific minimum detectable concentration (MDC).

LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

**Table 19 - Sampling Results**  
**Filtered Samples From Deep Wells**  
**Metals Page 4 of 5**

		B29W11D				B29W13D				LMW-04						LMW-04 (DUP)	
	Std (1)	Mar-01		Jun-01		Mar-01		Jun-01		Mar-01		Jun-01		Aug-02		Jun-01	
UNITS	mg/L	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Aluminum	NS	0.012	U	0.0076	U	0.019	U	0.015	U	0.0077	U	0.0076	U	0.0065	U	0.0076	U
Antimony	NS	0.0036	U	0.0021	B	0.006	U	0.0041	U	0.0029	B	0.0031	B	0.003	B	0.0021	U
Arsenic	0.05	0.0022	U	0.0015	U	0.0037	U	0.0032	B	0.0021	B	0.003	B	0.003	B	0.002	B
Barium	1	0.024	B	0.094		0.047	B	0.016	B	0.022	B	0.0062	B	0.0039	B	0.0042	B
Beryllium	NS	0.00016	U	0.0014		0.00027	U	0.0014	B	0.0005	B	0.00014	B	0.00074	B	0.00016	B
Boron	NS	1.8		1.7		0.46		1.1		0.84		0.64		0.77		0.79	
Cadmium	0.01	0.0003	U	8.40E-05	U	0.0005	U	0.00017		0.0002	U	0.00035	B	0.00014	U	8.40E-05	U
Calcium	NS	440		530		410		470		490		450		470		430	
Chromium	0.05	0.00051	U	0.00021	U	0.00085	U	0.00041	U	0.0021	B	0.00067	B	0.00091	B	0.00021	U
Cobalt	NS	0.00084	B	0.00037	U	0.0028	B	0.0027	B	0.0004	U	0.00044	B	0.00053	U	0.00037	U
Copper	NS	0.0005	U	0.00027	U	0.00084	U	0.00053	U	0.001	B	0.00027	U	0.0003	U	0.00027	U
Iron	NS	0.046	B	0.0061	U	0.11	B	0.013	B	8.1		0.06	B	0.0084	B	0.051	B
Lead	0.05	0.00098	U	0.0021	U	0.0016	U	0.0021	U	0.00098	U	0.0011	U	0.0031	U	0.0011	U
Magnesium	NS	120		140		68		120		160		140		150		140	
Manganese	NS	0.028		0.054		0.014	B	0.079		0.039		0.016		0.027		0.013	
Mercury	0.002	1.60E-05	U	3.30E-05	U	1.60E-05	U	3.30E-05	U	1.60E-05	U	3.30E-05	U	0.000011	U	3.30E-05	U
Molybdenum	0.1	0.0068	U	0.0038	U	0.011	U	0.013	B	0.021		0.0041		0.0032	U	0.01	
Nickel	NS	0.0009	U	0.00033	B	0.0015	U	0.00078	B	0.0014	B	0.00096	B	0.0028	B	0.0003	U
Potassium	NS	14		20		34		55		6.5		9.2		5.1		8.3	
Selenium	0.01	0.0037	U	0.0019	U	0.0062	U	0.0038	U	0.0025	U	0.0019	U	0.0036	U	0.0019	U
Silver	0.05	0.0011	B	0.00057	U	0.0012	U	0.0014	B	0.00063	B	0.00057	U	0.00042	U	0.00057	U
Sodium	NS	640		600		2300		2000		230		230		230		230	
Thallium	NS	0.0042	U	0.0054		0.007	U	0.0076	B	0.0028	U	0.0038	B	0.0041	U	0.0035	B
Vanadium	NS	0.00057	U	0.00038	U	0.00096	U	0.00075	U	0.00038	U	0.00038	U	0.00032	U	0.00038	U
Zinc	NS	0.0019	B	0.0075	B	0.0058	B	0.012	B	0.0016	B	0.0012	B	0.016		0.00031	U

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Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

**Table 19 - Sampling Results**  
**Filtered Samples From Deep Wells**  
**Metals Page 5 of 5**

		LMW-05						LMW-06						LMW-06 (DUP)	
	Std (1)	Mar-01		Jun-01		Aug-02		Mar-01		Jun-01		Aug-02		Aug-02	
UNITS	mg/L	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Aluminum	NS	0.0077	U	0.0076	U	0.0065	U	0.015	U	0.015	U	0.0065	U	0.0065	U
Antimony	NS	0.0024	U	0.0021	U	0.0029	U	0.0048	U	0.0041	U	0.0029	U	0.0029	U
Arsenic	0.05	0.0015	U	0.0017	B	0.0019	U	0.012	B	0.003	U	0.012		0.013	
Barium	1	0.019	B	0.013		0.0056	B	0.076		0.43		0.078		0.078	
Beryllium	NS	0.00055	B	0.00026	B	0.00021	U	0.0009	B	0.00036	B	0.00021	U	0.00021	U
Boron	NS	0.96		0.98		0.85		0.74		0.51		0.83		0.84	
Cadmium	0.01	0.0002	U	8.40E-05	U	0.00014	U	0.0004	U	0.00017	U	0.00014	U	0.00014	U
Calcium	NS	570		490		510		560		700		390		390	
Chromium	0.05	0.00034	U	0.00021	U	0.00032	U	0.0036	B	0.00074	B	0.00032	U	0.00032	U
Cobalt	NS	0.0004	U	0.00037	U	0.00053	U	0.00079	U	0.00073	U	0.00053	U	0.00053	U
Copper	NS	0.00034	U	0.00027	U	0.0003	U	0.00082	B	0.00053	U	0.0003	U	0.0003	U
Iron	NS	0.038	B	0.047	B	0.017	B	0.44		0.074	B	0.0072	U	0.0072	U
Lead	0.05	0.0013	U	0.0021	U	0.0031	U	0.0013	U	0.0021	U	0.0015	U	0.0015	U
Magnesium	NS	160		150		170		46		0.33	B	23		24	
Manganese	NS	0.0098	B	0.011		0.0096	B	0.032		8.80E-05	U	0.0043	B	0.0045	B
Mercury	0.002	1.60E-05	U	3.30E-05	U	1.10E-05	U	0.00028		3.30E-05	U	1.10E-05	B	1.10E-05	B
Molybdenum	0.1	0.0078	B	0.0038	U	0.0032	U	0.37		0.15		0.24		0.24	
Nickel	NS	0.0006	U	0.0003	U	0.00052	U	0.0035	B	0.0006	U	0.00052	U	0.00052	U
Potassium	NS	7.1		9.9		5.3		23		34		16		16	
Selenium	0.01	0.0025	U	0.0019	U	0.0036	U	0.005	U	0.0038	U	0.0036	U	0.0036	U
Silver	0.05	0.00048	U	0.00058	B	0.00042	B	0.0012	U	0.0011	U	0.00042	U	0.00042	U
Sodium	NS	260		260		230		1300		920		950		940	
Thallium	NS	0.0028	U	0.0048	B	0.0041	U	0.0056	U	0.0036	U	0.0041	U	0.0041	U
Vanadium	NS	0.00038	U	0.00038	U	0.00032	U	0.0022	B	0.0012	B	0.00071	B	0.0012	B
Zinc	NS	0.0043	B	0.0025	B	0.0039	B	0.013	B	0.0021	B	0.013		0.0069	B

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Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

**Table 20 - Sampling Results**  
**Unfiltered and Filtered Samples From Shallow Wells**  
**Metals page 1 of 2**

UNFILTERED		LMW-01						LMW-03					
	Std (1)	Mar-01		Jun-01		Aug-02		Mar-01		Jun-01		Aug-02	
UNITS	mg/L	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Aluminum	NS	0.039	U	0.3		8.9		0.016	B	0.0076	U	0.009	B
Antimony	NS	0.012	U	0.0041	U	0.0029	U	0.0024	U	0.0021	U	0.0034	B
Arsenic	0.05	0.0073	U	0.003	B	0.016		0.0041	B	0.0069		0.0037	B
Barium	1	0.83		0.12		0.096		0.03		0.028		0.02	
Beryllium	NS	0.0026	B	0.0011	B	0.00069	B	0.00078	B	0.00016	B	0.00035	B
Boron	NS	0.1	B	0.072	B	0.27		0.38		0.3		0.36	
Cadmium	0.01	0.001	U	0.0035		0.0091		0.0013	B	0.00065	B	0.00014	U
Calcium	NS	1300		460		340		260		230		230	
Chromium	0.05	0.047	B	0.0042	B	0.071		0.0036	B	0.0045	B	0.00032	U
Cobalt	NS	0.002	U	0.00073	U	0.0038	B	0.0014	B	0.00073	B	0.0015	B
Copper	NS	0.0082	B	0.00078	B	0.029		0.011		0.0014	B	0.0003	U
Iron	NS	1.2		0.19	B	7.9		7.1		1.9		0.89	
Lead	0.05	0.04		0.0021	U	0.034		0.0026	B	0.0011	U	0.0031	U
Magnesium	NS	12		120		500		470		400		540	
Manganese	NS	0.0029	B	0.026		0.65		0.65		0.49		0.41	
Mercury	0.002	1.60E-05	U	0.00013	B	0.00016	B	1.60E-05	U	3.30E-05	U	1.10E-05	U
Molybdenum	0.1	0.023	U	0.0075	U	0.025		0.036		0.029		0.012	
Nickel	NS	0.016	B	0.012	B	0.043		0.0076	B	0.0068	B	0.0027	B
Potassium	NS	66		67		9.5		13		13		9	
Selenium	0.01	0.012	U	0.0038	U	0.0036	U	0.0026	B	0.0019	U	0.0036	U
Silver	0.05	0.0024	U	0.0011	U	0.00051	B	0.00052	B	0.00057	U	0.00042	U
Sodium	NS	3600		1600		690		180		170		180	
Thallium	NS	0.014	U	0.0036	U	0.0041	U	0.0028	U	0.0031	B	0.0041	U
Vanadium	NS	0.0028	B	0.0011	B	0.03		0.0015	B	0.0012	B	0.00032	U
Zinc	NS	0.039	B	0.019	B	0.59		0.13		0.019		0.021	

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B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

**Table 20 - Sampling Results**  
**Unfiltered and Filtered Samples From Shallow Wells**  
**Metals page 2 of 2**

FILTERED		LMW-01						LMW-03					
	Std (1)	Mar-01		Jun-01		Aug-02		Mar-01		Jun-01		Aug-02	
UNITS	mg/L	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Aluminum	NS	0.039	U	0.015	U	0.0065	U	1.4	B	0.0076	U	0.011	B
Antimony	NS	0.012	U	0.0041	U	0.0029	U	0.0024	U	0.0021	U	0.0029	U
Arsenic	0.05	0.0073	U	0.003	U	0.0044	B	0.002	B	0.0029	B	0.005	B
Barium	1	0.97		0.11		0.046		0.051		0.063		0.02	
Beryllium	NS	0.002	B	0.00088	B	0.00021	U	0.00073	B	0.00011	B	0.00027	B
Boron	NS	0.067	B	0.077	B	0.13		0.45		0.4		0.33	
Cadmium	0.01	0.001	U	0.00017	U	0.00014	U	0.0002	U	8.40E-05	U	0.00014	U
Calcium	NS	1400		400		300		240		230		210	
Chromium	0.05	0.024	B	0.00041	U	0.00053	B	0.034		0.00021	B	0.00052	B
Cobalt	NS	0.002	U	0.00073	U	0.00053	U	0.002	B	0.001	B	0.001	B
Copper	NS	0.0073	B	0.00078	B	0.0003	U	0.0037	B	0.00027	U	0.0003	U
Iron	NS	0.74		0.19		0.021	B	1		0.75		0.43	
Lead	0.05	0.0033	U	0.0021	U	0.0015	U	0.0013	U	0.0011	U	0.0015	U
Magnesium	NS	0.85	B	250		330		530		490		500	
Manganese	NS	0.00045	U	0.0091	B	0.16		0.67		0.45		0.34	
Mercury	0.002	1.60E-05	U	3.30E-05	U	1.10E-05	U	1.60E-05	U	3.30E-05	U	1.10E-05	U
Molybdenum	0.1	0.023	U	0.015	B	0.014		0.02		0.018		0.015	
Nickel	NS	0.0033	B	0.0034	B	0.0021	B	0.029		0.0021	B	0.0048	B
Potassium	NS	69		40		4.8		13		15		8.3	
Selenium	0.01	0.012	U	0.0038	U	0.0036	U	0.0025	U	0.0019	U	0.0036	U
Silver	0.05	0.0024	U	0.0011	U	0.00042	U	0.00062	B	0.00057	U	0.00042	U
Sodium	NS	3900		1300		790		180		180		170	
Thallium	NS	0.014	U	0.0078	B	0.0041	U	0.0028	U	0.0018	U	0.0041	U
Vanadium	NS	0.0039	B	0.0011	B	0.00047	B	0.0013	B	0.00038	U	0.00032	U
Zinc	NS	0.013	B	0.019	B	0.0033	B	0.015	B	0.014		0.0047	B

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Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

**Table 21 - Sampling Results**  
**Unfiltered Samples From Deep Wells**  
**General Chemistry Page 1 of 2**

UNFILTERED	B29W01D				B29W03D				B29W05D			
	Mar-01		Jun-01		Mar-01		Jun-01		Mar-01		Jun-01	
UNITS	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Bicarbonate as CaCO <sub>3</sub>	53		49		83		92		5	U	10	U
Carbonate as CaCO <sub>3</sub>	5	U	10	U	5	U	10	U	29		39	
Chloride	350		330		130		120		1100		1100	
Fluoride	1.2		1.1		1.9		1.6		1.2		1.3	
Nitrate	0.5	U	0.5	U	0.5	U	0.66		0.5	U	1	U
Orthophosphate	0.5	U	0.5	U	0.5	U	0.5	U	0.5	U	1	U
Sulfate	2700		2400		2400		2200		2500		2300	
Total Dissolved Solids	4300		4100		3500		3400		5100		5200	
Total Organic Carbon	3		1.7		1	U	1	U	1.2		1	U

UNFILTERED	B29W07D				B29W07D (DUP)				B29W09D				B29W09D (DUP)	
	Mar-01		Jun-01		Mar-01		Jun-01		Mar-01		Jun-01		Mar-01	
UNITS	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Bicarbonate as CaCO <sub>3</sub>	5	U	10		5	U	10	U	5	U	10	U	5	U
Carbonate as CaCO <sub>3</sub>	36		36		30		38		32		37		30	
Chloride	2000		1700		2000		1700		2200		2200		2100	
Fluoride	1.4		1.3		1.4		1.4		1	U	2	U	1	U
Nitrate	1	U	1	U	1	U	1	U	1	U	2	U	1	U
Orthophosphate	1	U	1	U	1	U	1	U	1	U	2	U	1	U
Sulfate	4300		3700		4400		3600		9300		9300		9300	
Total Dissolved Solids	8500		8200		8500		7900		15000		16000		15000	
Total Organic Carbon	1	U	1.7		2.1		1.7		2.8		1.5		1.6	

Qual = Data qualifier included in report from the laboratory.

U means the result is less than the sample specific minimum detectable concentration (MDC).

LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

**Table 21 - Sampling Results**  
**Unfiltered Samples From Deep Wells**  
**General Chemistry Page 2 of 2**

UNFILTERED	B29W10D				B29W11D				B29W13D			
	Mar-01		Jun-01		Mar-01		Jun-01		Mar-01		Jun-01	
UNITS	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Bicarbonate as CaCO <sub>3</sub>	17		10	U	32		22		5	U	10	U
Carbonate as CaCO <sub>3</sub>	5	U	20		5	U	10	U	24		33	
Chloride	2200		1600		570		540		1600		1400	
Fluoride	2.9		2.7		1.5		2.3		1.1		1.1	
Nitrate	1	U	1	U	0.5	U	1.9		1	U	1	U
Orthophosphate	1	U	1	U	0.5	U	1	U	1	U	1	U
Sulfate	1800		1100		2800		2600		5600		4800	
Total Dissolved Solids	5500		4300		4700		4700		9600		9100	
Total Organic Carbon	5.1		3.2		1	U	1	U	1.4		1	U

UNFILTERED	LMW-04				LMW-04 (DUP)		LMW-05				LMW-06			
	Mar-01		Jun-01		Jun-01		Mar-01		Jun-01		Mar-01		Jun-01	
UNITS	MG/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Bicarbonate as CaCO <sub>3</sub>	21		43		44		32		37		24		10	U
Carbonate as CaCO <sub>3</sub>	19		10	U	10	U	5	U	10	U	14		42	
Chloride	260		220		230		320		270		2100		1700	
Fluoride	2		1.7		1.8		2		1.8		2.6		1.5	
Nitrate	0.5	U	0.5	U	0.5	U	0.5	U	0.5	U	1	U	1	U
Orthophosphate	0.5	U	0.5	U	0.5	U	0.5	U	0.5	U	1	U	1	U
Sulfate	2000		1800		1800		2300		1900		2400		1100	
Total Dissolved Solids	3100		3100		3100		3500		3400		6000		4700	
Total Organic Carbon	2.2		1.1		1	U	6.5		2.8		4.8		5	

Qual = Data qualifier included in report from the laboratory.

U means the result is less than the sample specific minimum detectable concentration (MDC).

LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.



**Table 22 - Sampling Results**  
**Unfiltered Samples From Shallow Wells**  
**General Chemistry**

UNFILTERED	LMW-01				LMW-03			
	Mar-01		Jun-01		Mar-01		Jun-01	
UNITS	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL	mg/L	QUAL
Bicarbonate as CaCO <sub>3</sub>	50	U	10	U	490		370	U
Carbonate as CaCO <sub>3</sub>	70		58		50	U	10	U
Chloride	11000		4300		37		33	
Fluoride	2	U	1	U	0.78		0.75	
Nitrate	2	U	1	U	0.5	U	0.5	U
Orthophosphate	2	U	1	U	0.5	U	0.5	U
Sulfate	240		480		2400		2100	
Total Dissolved Solids	14000		7700		3700		3300	
Total Organic Carbon	4.8		6.7		14		5.7	

Qual = Data qualifier included in report from the laboratory.

U means the result is less than the sample specific minimum detectable concentration (MDC).

LT means the result is less than the requested MDC, but greater than the sample specific MDC.

Y1 means the chemical yield in control at 100-110%. Quantitative yield is assumed.

B means analyte concentration is greater than the Instrument Detection Limit (IDL), but less than the required reportable quantity.

**Table 23**  
**GROUNDWATER STANDARDS - 40 CFR PART 192, SUBPART A**

<b>Constituent (1)</b>	<b>Maximum</b>
Arsenic	0.05
Barium	1
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Selenium	0.01
Silver	0.05
Nitrate (as N)	10
Molybdenum	0.1
Combined Radium-226 and Radium-228	5 pCi/L
Combined Uranium-234 and Uranium-238 <sup>(2)</sup>	30 pCi/L
Gross Alpha-particle Activity (excluding radon and uranium)	15 pCi/L
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2, 4-D	0.1
2, 4, 5-TP Silvex	0.01

**Notes:**

(1) Milligrams per liter, unless stated otherwise.

(2) Where secular equilibrium obtains, this criterion will be satisfied by a concentration of 0.044 milligrams per liter (0.044 mg/L). For conditions of other than secular equilibrium, a corresponding value may be derived and applied, based on the measured site-specific ratio of the two isotopes of uranium.

**Table 24 - Sampling Results**  
**Unfiltered and Filtered Samples From Deep Wells**  
**Gross  $\alpha$ , U-234 + U-238, and Ra-226 + Ra-228**

**UNFILTERED**

Analytes	Gross $\alpha$ (4)			U-234 + U-238			Ra-226 + Ra-228		
Standard (1)	15	15	15	30	30	30	5	5	5
Units	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L
WELL	Mar-01	Jun-01	Aug-02	Mar-01	Jun-01	Aug-02	Mar-01	Jun-01	Aug-02
B29W01D	11	1	N/A	1.69	0.85	N/A	2.5	2.2	N/A
B29W03D	3	11	N/A	0.77	0.88	N/A	3.3	-0.4	N/A
B29W05D	-8	9	-7	0.89	0.16	0.58	1.3	2.1	1.4
B29W07D	-1	-6	0	0.18	0.79	0.49	1.3	3.0	1.1
B29W07D (DUP)	8	16	N/A	0.14	0.58	N/A	0.9	2.4	N/A
B29W09D	-13	52	-11	0.72	1.13	1.40	1.2	1.9	1.3
B29W09D (DUP)	7	N/A	N/A	1.30	N/A	N/A	1.4	N/A	N/A
B29W10D	-216	-16	N/A	671	23	N/A	1.7	0.5	N/A
B29W11D	-2	-1	N/A	0.45	0.27	N/A	2.0	2.0	N/A
B29W13D	8	9	N/A	0.16	0.16	N/A	0.9	1.6	N/A
LMW-04	-9	3	-3	21.10	4.25	5.78	1.4	1.0	1.5
LMW-04 (DUP)	N/A	-2	N/A	N/A	4.68	N/A	N/A	0.3	N/A
LMW-05	12	6	-3	14.90	9.10	5.75	5.4	4.4	2.2
LMW-06	-140	11	-20	544	14	63.20	70.0	2.6	2.0
LMW-06 (DUP)	N/A	N/A	-34	N/A	N/A	66.10	N/A	N/A	2.2

**FILTERED**

Analytes	Gross $\alpha$ (4)			U-234 + U-238			Ra-226 + Ra-228		
Standard (1)	15	15	15	30	30	30	5	5	5
Units	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L
WELL	Mar-01	Jun-01	Aug-02	Mar-01	Jun-01	Aug-02	Mar-01	Jun-01	Aug-02
B29W01D	2	3	N/A	0.44	0.88	N/A	1.1	0.8	N/A
B29W03D	2	10	N/A	0.53	0.12	N/A	2.8	3.1	N/A
B29W05D	-2	27	2	0.44	0.16	0.40	1.8	1.0	1.75
B29W07D	-2	4	-6	0.12	0.03	0.34	1.4	0.8	1.51
B29W07D (DUP)	-1	1	N/A	0.01	0.06	N/A	0.9	1.2	N/A
B29W09D	-20	36	-22	0.73	0.78	0.37	2.4	1.1	1.4
B29W09D (DUP)	-17	N/A	N/A	0.78	N/A	N/A	1.0	N/A	N/A
B29W10D	-116	-7	N/A	332	2.87	N/A	3.8	1.1	N/A
B29W11D	10	3	N/A	0.73	0.20	N/A	1.4	1.9	N/A
B29W13D	-17	7	N/A	0.21	0.25	N/A	1.2	1.4	N/A
LMW-04	-9	4	-6	20.30	3.88	5.12	0.8	2.0	0.74
LMW-04 (DUP)	N/A	-1	N/A	N/A	4.79	N/A	N/A	1.1	N/A
LMW-05	-5	1	-3	12.30	5.43	4.32	2.3	1.0	1.22
LMW-06	-125	2	-4	339	0.26	31.50	1.7	1.4	1.65
LMW-06 (DUP)	N/A	N/A	-8	N/A	N/A	37.30	N/A	N/A	1.32

(1) The standard is the groundwater standard of 40 CFR Part 192.

(2) The results in this table represent the sum of individual results.

For qualifiers, refer to individual radium, uranium, and Gross  $\alpha$  results.

(3) Results exceeding the 40 CFR Part 192 standard are shaded in this table.

(4) Excluding uranium (U-234 + U-235 + U-238).

N/A means not applicable, sample was not collected for the date indicated.

**Table 25 - Sampling Results**  
**Unfiltered and Filtered Samples From Shallow Wells**  
**Gross  $\alpha$ , U-234 + U-238, and Ra-226 + Ra-228**

**UNFILTERED**

<b>Analytes</b>	<b>Gross <math>\alpha</math> (4)</b>			<b>U-234 + U-238</b>			<b>Ra-226 + Ra-228</b>		
<b>Standard (1)</b>	<b>15</b>	<b>15</b>	<b>15</b>	<b>30</b>	<b>30</b>	<b>30</b>	<b>5</b>	<b>5</b>	<b>5</b>
Units	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L
<b>WELL</b>	<b>Mar-01</b>	<b>Jun-01</b>	<b>Aug-02</b>	<b>Mar-01</b>	<b>Jun-01</b>	<b>Aug-02</b>	<b>Mar-01</b>	<b>Jun-01</b>	<b>Aug-02</b>
LMW-01	13.9	-2.5	-4.5	0.1	6.39	12.5	2.1	1.6	0.8
LMW-03	-20.0	-9.3	-22.1	34.5	29.6	31.1	1.6	0.9	0.8

**FILTERED**

<b>Analytes</b>	<b>Gross <math>\alpha</math> (4)</b>			<b>U-234 + U-238</b>			<b>Ra-226 + Ra-228</b>		
<b>Standard (1)</b>	<b>15</b>	<b>15</b>	<b>15</b>	<b>30</b>	<b>30</b>	<b>30</b>	<b>5</b>	<b>5</b>	<b>5</b>
Units	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L
<b>WELL</b>	<b>Mar-01</b>	<b>Jun-01</b>	<b>Aug-02</b>	<b>Mar-01</b>	<b>Jun-01</b>	<b>Aug-02</b>	<b>Mar-01</b>	<b>Jun-01</b>	<b>Aug-02</b>
LMW-01	24.1	22.7	-11.8	0.01	1.2	12.4	2.7	1.7	1.2
LMW-03	-15.8	-4.7	-21.8	30.5	29.3	26.7	2.5	1.0	0.7

- (1) The standard is the groundwater standard of 40 CFR Part 192.  
(2) The results in this table represent the sum of individual results.  
For qualifiers, refer to individual radium, uranium, and Gross  $\alpha$  results.  
(3) Results exceeding the 40 CFR Part 192 standard are shaded in this table.  
(4) Excluding uranium (U-234 + U-235 + U-238).  
N/A means not applicable, sample was not collected for the date indicated.

**Table 26 - Deep Wells**  
**March 2001, June 2001, and August 2002 Sample Results Exceeding**  
**40 CFR Part 192 Groundwater Standards (1)**

Analyte	Deep Wells - March 2001									Deep Wells - June 2001				Deep Wells - August 2002					
	Ra-226+Ra-228	U-234 + U-238	U-234 + U-238	Uranium (total)	Uranium (total)	Molybdenum	Molybdenum	Chromium	Mercury	Gross Alpha (2)	Gross Alpha (2)	Molybdenum	Molybdenum	U-234 + U-238	U-234 + U-238	Uranium (total)	Uranium (total)	Molybdenum	Molybdenum
40 CFR Part 192 Standard	5 pCi/L	30 pCi/L	30 pCi/L	44 µg/L	44 µg/L	0.1 mg/L	0.1 mg/L	0.05 mg/L	0.002 mg/L	15 pCi/L	15 pCi/L	0.1 mg/L	0.1 mg/L	30 pCi/L	30 pCi/L	44 µg/L	44 µg/L	0.1 mg/L	0.1 mg/L
Preparation	Unf.	Unf.	Fil.	Unf.	Fil.	Unf.	Fil.	Unf.	Unf.	Unf.	Fil.	Unf.	Fil.	Unf.	Fil.	Unf.	Fil.	Unf.	Fil.
Date	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Mar-01	Jun-01	Jun-01	Jun-01	Jun-01	Aug-02	Aug-02	Aug-02	Aug-02	Aug-02	Aug-02
Units	pCi/L	pCi/L	pCi/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	pCi/L	pCi/L	mg/L	mg/L	pCi/L	pCi/L	µg/L	µg/L	mg/L	mg/L
Well																			
B29W05D	1.3	0.89	0.44	1.43	0.52	ND	0.008	0.002	ND	9	27	ND	ND	0.58	0.4	0.106	0.166	ND	ND
B29W07D	1.3	0.18	0.12	0.21	0.09	0.048	0.053	0.002	ND	16	4	0.033	0.053	0.49	0.34	0.731	0.361	0.033	0.036
B29W09D	1.4	1.3	0.78	2.36	1.92	0.44	0.45	ND	ND	52	36	0.42	0.42	1.4	0.37	1.06	0.63	0.33	0.34
B29W10D	1.4	671	332	765	470	0.25	0.24	0.096	0.013	-16	-7	0.22	0.20	N/A	N/A	N/A	N/A	N/A	N/A
LMW-05	5.4	14.9	2.3	26.6	18.1	0.008	0.008	ND	ND	6	1	0.008	ND	5.75	4.32	9.04	7.79	ND	ND
LMW-06	70	544	339	837	390	0.37	0.37	0.004	0.0003	11	2	0.15	0.15	66.1	37.3	98.8	62.9	0.27	0.24

(1) Results exceeding the 40 CFR Part 192 standards are shaded in this table.

(2) Gross  $\alpha$  excluding uranium

ND = Not detected.

N/A means not applicable, sample was not collected for the date indicated.

Unf. = Unfiltered sample

Fil. = Filtered sample

**Table 27 - Shallow Wells**  
**March 2001, June 2001, and August 2002 Sample Results Exceeding**  
**40 CFR Part 192 Groundwater Standards (1)**

	Shallow Wells March 2001			Shallow Wells June 2001	Shallow Wells August 2002
Analyte	Gross Alpha (2)	U-234 + U-238	U-234 + U-238	Gross Alpha (2)	U-234 + U-238
40 CFR Part 192 Standard	15 pCi/L	30 pCi/L	30 pCi/L	15 pCi/L	30 pCi/L
Preparation	Fil.	Unf.	Fil.	Fil.	Unf.
Date	Mar-01	Mar-01	Mar-01	June	August
Units	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L
Well					
LMW-01	24.1	0.1	0.01	22.7	12.5
LMW-03	-16	34.5	30.5	-5	31.1

(1) Results exceeding the 40 CFR Part 192 pCi/L standards are shaded in this table.

(2) Gross  $\alpha$  excluding uranium

Unf. = Unfiltered sample

Fil. = Filtered sample

**Table 28 - Results of Soils and Leachate Analyses - August 2002 and March 2001 Samples**

Matrix		Soil	Cal WET	Mod Cal WET	Soil	Cal WET	Mod Cal WET	Soil	Cal WET	Mod Cal WET	Soil	Cal WET	Mod Cal WET
Analyte		U-234	U-234	U-234	U-235	U-235	U-235	U-238	U-238	U-238	U-TOT*	U-TOT*	U-TOT*
Units		pCi/g	pCi/L	pCi/L	pCi/g	pCi/L	pCi/L	pCi/g	pCi/L	pCi/L	pCi/g	pCi/L	pCi/L
Location	Sample No.												
<b>August 2002 Samples</b>													
Class 1 (Building 30 Post Remediation)	LISB0010	0.81	9.5	0.24	0.08	1.06	0.13	0.78	7.4	0.112	1.67	17.96	0.48
Class 1 (Building 30 Post Remediation) (Duplicate of above)	LISB9002 (DUP)	0.93	8	0.19	0.06	0.46	0.09	0.87	7.7	0.1	1.86	16.16	0.38
Class 1 (Building 30 Post Remediation)	LISB0011	0.84	9.5	0.09	0.06	0.53	0.034	0.80	7.7	0.049	1.70	17.73	0.17
Class 2	LISB0012	11.00	662	80	1.38	57	7.4	10.70	633	66	23.08	1352.00	153.40
Class 2	LISB0013	0.91	14.9	0.2	0.06	1.14	0.13	0.91	12.9	0.22	1.88	28.94	0.55
<b>March 2001 Samples</b>													
Bldg 30 Footprint	LISB0001	4,940	123,000	NA	228	7,000	NA	4,690	125,000	NA	9,858	255,000	NA
Bldg 30 Footprint	LISB9001 (DUP)	5,170	124,000	NA	291	7,300	NA	5,450	123,000	NA	10,911	254,300	NA
Bldg 30 Footprint	LISB0002	90	3,210	NA	4.19	195	NA	91	3,190	NA	185.19	6,595	NA
Bldg 73B Excavation	LISB0003	2.36	16.4	NA	0.18	0.83	NA	2.38	13.4	NA	4.92	30.63	NA
Bldg 73B Excavation	LISB0004	3.55	43	NA	0.21	1.9	NA	3.8	42.2	NA	7.56	87.1	NA
Bldg 73B Excavation	LISB0005	27.8	404	NA	2.55	16	NA	28.1	398	NA	58.45	818	NA

Matrix		Soil	Cal WET	Mod Cal WET	Soil	Cal WET	Mod Cal WET	Soil	Cal WET	Mod Cal WET	Soil	Cal WET	Mod Cal WET
Analyte		Ra-226	Ra-226	Ra-226	Ra-228	Ra-228	Ra-228	Ra-226 + Ra-228	Ra-226 + Ra-228	Ra-226 + Ra-228	Th-230	Th-230	Th-230
Units		pCi/g	pCi/L	pCi/L	pCi/g	pCi/L	pCi/L	pCi/g	pCi/L	pCi/L	pCi/g	pCi/L	pCi/L
Location	Sample No.												
<b>August 2002 Samples</b>													
Class 1 (Building 30 Post Remediation)	LISB0010	1.18	15.4	0.02	0.76	19.1	0.04	1.94	34.50	0.06	0.88	14.5	0.36
Class 1 (Building 30 Post Remediation) (Duplicate of above)	LISB9002 (DUP)	1.02	15.9	0.03	0.87	21.9	-0.05	1.89	37.80	-0.02	0.92	14.5	0.31
Class 1 (Building 30 Post Remediation)	LISB0011	1.33	17.4	0.05	0.82	21.6	0.11	2.15	39.00	0.16	1.17	19.6	R
Class 2	LISB0012	2.51	22.2	0.06	1.09	16.4	0.17	3.60	38.60	0.23	2.13	55.1	0.289
Class 2	LISB0013	1.13	12	0	0.74	18.8	0.34	1.87	30.80	0.34	1.01	R	R
<b>March 2001 Samples</b>													
Bldg 30 Footprint	LISB0001	15.4	49.1	NA	2.05	0.17	NA	17.45	49.27	NA	75	1970	NA
Bldg 30 Footprint	LISB9001 (DUP)	16.7	37	NA	0.69	2.5	NA	17.39	39.50	NA	35.5	1940	NA
Bldg 30 Footprint	LISB0002	4.78	80.9	NA	0.83	2.7	NA	5.61	83.60	NA	4.05	123	NA
Bldg 73B Excavation	LISB0003	2.59	11.7	NA	1.9	8.7	NA	4.49	20.40	NA	2.58	6.66	NA
Bldg 73B Excavation	LISB0004	3.92	29.5	NA	0.72	3.3	NA	4.64	32.80	NA	3.84	68	NA
Bldg 73B Excavation	LISB0005	5.23	68.6	NA	1.31	5.3	NA	6.54	73.90	NA	11	299	NA

Notes:

Class 1 = Areas where active soil remediation (soil removal) has occurred or where active remediation is ongoing. Collected from Building 30 excavation (below slab).

Class 2 = Areas that laterally bound Class 1 areas and contain soils that are not impacted by radioactive materials above the action levels.

Cal WET = Leachate - California Waste Extraction Test. Extraction fluid pH = 5

Mod Cal WET = Leachate - Modified California Waste Extraction Test, performed August 2002 only. Extraction fluid pH = 7.95 (same as the groundwater).

\*U-TOT =  $\Sigma$  U-234 + U-235 + U-238

R = Result rejected by during data validation

DUP = Duplicate sample taken

NA = Not applicable, test not conducted for the sample indicated

**Table 29 - Well and Groundwater Elevations  
March 2001, June 2001 and August 2002**

<b>Well</b>	<b>Groundwater Elevation (ft)</b>	<b>Groundwater Elevation (ft)</b>	<b>Groundwater Elevation (ft)</b>
<b>Shallow Wells</b>	<b>March 2001</b>	<b>June 2001</b>	<b>August 2002</b>
LMW-01	600.70	598.13	600.53
LMW-02*	594.12	597.44	595.92
LMW-03	595.54	595.23	595.44
<b>Deep Wells</b>			
LMW-04	566.68	566.74	565.75
LMW-05	566.78	566.57	565.54
LMW-06	566.61	566.56	565.82
B29W01D	566.71	566.75	NM
B29W03D	566.88	566.77	NM
B29W05D	566.59	566.7	565.91
B29W07D	566.95	566.98	565.80
B29W09D	566.64	566.56	565.58
B29W010D	566.80	566.95	NM
B29W011D	566.91	567.18	NM
B29W013D	566.52	566.65	NM

\* Well was not sampled due to low recharge.

Elevations are referenced to mean sea level.

NM = Not measured



## **APPENDIX B**

### **GEOCHEMICAL MODELING AND EVALUATION OF URANIUM TRANSPORT**

## APPENDIX B

### GEOTECHNICAL MODELING AND EVALUATION OF URANIUM TRANSPORT

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## 1.0 GEOCHEMICAL MODELING

### 1.1 Overview

Geochemical modeling was conducted to evaluate the hypothesis that mixing of high pH, high temperature process water with lower pH, lower temperature groundwater in the contact zone aquifer at Linde could result in precipitation of uranium compounds. The approach included review of process history and injection practices, review of geohydrologic characterization of the site and use of the PHREEQC geochemical model (Parkhurst and Appelo 1999) to investigate variation of the solubility of uranium with conditions occurring at the site. Data used in the analysis, results of the analysis and a summary of evidence regarding movement of uranium at the Linde Site are presented in the following sections.

### 1.2 Site Conditions for Geochemical Modeling

The primary cations present in site groundwater are calcium, magnesium, potassium and sodium with lesser amounts of iron. The primary anions observed at the site are bicarbonate, carbonate, chloride and sulfate. Groundwater temperatures measured in the field ranged from 9 to 20 degrees Celsius (°C) while pH ranges from 7 to 11, with the higher values observed in the vicinity of injection wells. Because of observation of a uranium precipitate in the rock core from boring LIWRO-01 (drilled during the second phase of the RI – 1990-1991), conditions representative of the southern portion of the site (in the vicinity of the injection wells near Building 8) were selected for investigation of uranium solubility.

Concentrations of dissolved constituents measured in wells in the southern portion of the site are similar. Thus, the chemical composition of groundwater from a well near LIWRO-01 (LMW-06) was used as the basis for the analysis. Values of temperature, pH and oxidation state (Eh) selected as representative conditions are those from wells expected to reflect undisturbed conditions in the contact zone aquifer at the onset of precipitation. Composition and conditions for the representative groundwater used in the analysis are summarized in Table 1.

**Table 1. Characteristics of Representative Groundwater at the Linde Site**

Parameter	Value
Temperature (°C)	18.0
pH	8.0
Eh (mV)	-188
Cation Concentration (mg/L)	
Na	920
K	34
Mg	0.33
Ca	700
F	0.074
Anion Concentration (mg/L)	
Cl	1770
SO <sub>4</sub>	1190
Alkalinity (as HCO <sub>3</sub> )	63.4

### 1.3 Results

Results generated in geochemical modeling using the PHREEQC computer code included identification of aqueous and solid phase components important at the site and estimation of the solubility of uranium for a range of conditions relevant to the site. The initial step in the analysis was identification of the distribution of elements among ionic species in the groundwater. For the initial conditions summarized in Table 1, PHREEQC predicted that dissolved carbon was present mainly as bicarbonate ( $\text{HCO}_3^-$ ) and calcium carbonate ( $\text{CaCO}_3$ ) and the solution was oversaturated with respect to the solid phase calcite ( $\text{CaCO}_3$ ) and slightly under-saturated with respect to gypsum ( $\text{CaSO}_4 \cdot \text{H}_2\text{O}$ ).

Results of the estimation of the solubility of uranium, reflecting the complex behavior of uranium as a function of pH and Eh, are summarized in Table 2. Under the neutral pH and reducing conditions (pH = 7 and Eh = - 200 mV) anticipated in the undisturbed contact zone aquifer, the solubility of uranium is relatively low at 0.04 mg/L, equivalent to approximately 27 pCi/L. Uranium was present in the aqueous phase primarily in hydroxide forms  $[\text{U}(\text{OH})_5^-]$  and the controlling solid was the lower valence form, uraninite ( $\text{UO}_2$ ). As pH is increased under reducing conditions, the predicted solubility increases and  $\text{U}_3\text{O}_8$  becomes the stable solid phase. Calculations performed for oxidizing conditions (Eh = + 500 mV) provide perspective on consistency of the analysis with reported injection conditions. For oxidizing conditions, solubility is high, aqueous uranium was present primarily in carbonate forms  $[\text{UO}_2(\text{CO}_3)_3^{4-}]$  and schoepite  $[\text{UO}_2(\text{OH})_2 \cdot \text{H}_2\text{O}]$  became the stable solid phase.

The results of geochemical modeling summarized above are consistent with the hypothesis that uranium soluble under process conditions could precipitate under conditions occurring in the contact zone aquifer.

**Table 2. Estimates of Solubility of Uranium at the Linde Site<sup>1</sup>**

pH	Eh = - 200 mV		Eh = + 500 mV	
	Uranium Solubility (mg/L)	Stable Solid Phase	Uranium Solubility (mg/L)	Stable Solid Phase
7	0.04	$\text{UO}_2$	20.0	$\text{UO}_2(\text{OH})_2 \cdot \text{H}_2\text{O}$
8	0.35	$\text{UO}_2$	18.0	$\text{UO}_2(\text{OH})_2 \cdot \text{H}_2\text{O}$
10	3.75	$\text{U}_3\text{O}_8$	5.0	$\text{UO}_2(\text{OH})_2 \cdot \text{H}_2\text{O}$
11	1.75	$\text{U}_3\text{O}_8$	0.0015	$\text{UO}_2(\text{OH})_2 \cdot \text{H}_2\text{O}$

<sup>1</sup> To convert concentrations in mg/L to pCi/L (approximately), multiply by 677.

### 1.4 Summary of Evidence

Evidence regarding the potential for groundwater transport of uranium at the Linde site may be grouped into the three categories:

- geochemical conditions,
- observations of well sediments and solids, and
- geochemical modeling results.

The geochemical conditions presented in Appendix A of the FS report, are summarized, in part, in Table 3. The data are grouped according to observation wells under the influence of the cluster of injection wells near Buildings 30 and 38 (northern portion of the site) and the cluster of injection wells near Building 8 (southern portion of the site). The data indicate that lower values of pH are associated with wells more distant from injection areas, while higher values of pH are associated with wells in injection areas. For the northern injection area, higher values of dissolved solids are found near injection wells

than in wells located at greater distances from injection wells. For the southern injection area, similar concentrations of anions and cations are found at injection and observation areas.

For concentrations of dissolved uranium, low values are reported for both injection and observation areas in the northern and southern areas. This premise is based on data for samples collected on June 1, 2001.

Concentration of uranium in sediment collected from well B29W09D (sampling in 1992, during RI), located in the northern injection area, was reported as 452 pCi/g while filtered and unfiltered groundwater samples from this well report background levels of uranium. Concentration of uranium in solids collected from well LIWRO-01 in the southern injection area was reported as 176 pCi/g. Concentrations of total uranium from wells LMW-06 and B29W10D (sampled in 2001) in the southern injection area in unfiltered samples are approximately an order of magnitude higher than values reported for filtered samples from these wells.

The site-monitoring program has shown high concentrations of uranium in sediment and low concentrations of uranium in water. The geochemical model has predicted low solubility at low pH under reducing conditions and high solubility at high pH conditions. These experimental and theoretical results support the premise that uranium is remaining in the solid phase in the Linde Site groundwater and the uranium is relatively insoluble.

**Table 3. Summary of Geochemical Conditions at the Linde Site**

<b>Well Location</b>	<b>pH</b>	<b>Concentration of Sodium (mg/L)</b>	<b>Concentration of Sulfate (mg/L)</b>	<b>Concentration of Uranium<sup>1</sup> (µg/L)</b>
Near Source B29W09D	9.0	4,000	9,300	0.5
B29W13D	10.0	1,900	4,800	0.2
Downgradient B29W03D	8.0	180	2,200	0.4
Near Source LMW-06	9.1	920	1,100	0.2
B29W10D	9.4	820	1,100	3.6
Downgradient LMW-04	7.4	230	1,800	5.3
LMW-05	7.8	260	1,900	6.7
B29W05D	7.8	990	2,300	0.1

<sup>1</sup>Data are for June 1, 2001 filtered samples.

## **2.0 EVALUATION OF URANIUM TRANSPORT**

### **2.1 Overview**

The objective of this analysis is to evaluate the potential for migration of uranium injected into the contact zone aquifer at the Linde site. This potential may be evaluated through review and categorization of monitoring data and through geochemical and groundwater modeling techniques. Because of limited data on geohydrologic conditions at the site and in characterization of the location of injected material, groundwater modeling provides perspective on modes of movement of uranium at the site rather than definitive projections of concentrations of uranium in the aquifer. Geochemical analysis performed using

the PHREEQC model has indicated that uranium may have low solubility at conditions expected in the contact zone aquifer.

## 2.2 Review of Well Monitoring Data

Review of the monitoring data from the 2001 investigation at Linde involved identification of evidence of contamination at wells near injection wells and at wells more distant from these sources. Radiological analysis of core materials from wells located near the sources has indicated the presence of uranium. Injection wells are located near Building 30 in the northern portion of the site and near Building 8 in the southern portion of the site. Results of this review are summarized in Table 4. In the northern portion of the site, the primary evidence of contamination in monitoring data is high dissolved solids content in well B29W09D located near the injection wells. Levels of uranium, both dissolved and suspended, are low for wells near and more distant from the injection wells. In the southern portion of the site, the primary evidence of contamination in monitoring data is high pH and levels of suspended uranium in samples from wells B29W10D and LMW-06 located near the injection wells. Indicators of contamination; (including pH, dissolved solids content and levels of uranium) are at background levels in wells removed from the source of contamination. Available monitoring data indicates that uranium is remaining near the sources at the Linde site.

**Table 4. Summary of Evidence of Contamination in Well Monitoring Data at the Linde Site<sup>1</sup>**

Location	Well Identification Code	pH	Total Dissolved Solids (mg/L)	Total Uranium Concentration	
				Filtered (µg/L)	Unfiltered (µg/L)
Upgradient, North					
	B29W07D	9	8,200	0.04	1.56
	B29W11D	9	4,700	0.19	0.31
Near Source, North					
	B29W09D	9	16,000	0.45	1.81
Downgradient, North					
	B29W03D	8	3,400	0.4	0.27
Near Source, South					
	B29W10D	12	4,300	3.63	24.8
	LMW-06	13	4,700	0.24	17.9
Down Gradient, South					
	B29W05D	9	5,200	0.08	0.34
	LMW-04	8	3,100	6.39	6.92
	LMW-05	8	3,400	6.73	8.9

<sup>1</sup>Data from samples collected in June 2001

## 2.3 Groundwater Modeling

Application of groundwater modeling involved development of a conceptual model of the site appropriate to the level of available data, selection of a transport model to describe the proposed concept and execution of the model. The conceptual model applied for this analysis envisions a mass of uranium injected into a localized volume of a contact zone aquifer comprising two layers, a basal overburden of sand and gravel and a zone of fractured shale. Hydraulic gradient for the horizontal direction is reported as 0.0003 ft/ft (USACE 2000). The hydraulic conductivity and porosity of the basal overburden and fractured shale are estimated (USACE 2000) as 2,400 ft/yr and 0.13 and 80 ft/yr and 0.001, respectively. Average linear velocities of groundwater estimated using these data are 5.5 and 24 ft/yr for the basal

overburden and fractured shale, respectively. Distribution coefficients of uranium measured at a site having similar soils are approximately 10 mg/L for both sand and gravel and glacial till (Dames and Moore 1995).

Movement of uranium may occur within the basal overburden, homogeneous shale or within gypsum layers in the shale. Based on the above data, movement of uranium through the basal overburden is expected to slow, moving at a rate of approximately 180 times less than the average linear velocity of the groundwater. Movement through homogeneous shale is also expected to be slow due to low hydraulic conductivity and moderate retention of uranium on shale. Depending on the value of porosity of the shale, the rate of movement of uranium could be a factor of thousands less than the rate of movement of groundwater. Within the fractured shale, groundwater flow is reported to occur through solution cavities in gypsum layers (USACE 1999). Significant retardation of movement of uranium may not occur within these solution cavities. Based on the above considerations, the most likely flow path for uranium affecting nearby monitoring wells is for unretarded flow through gypsum layers in the upper portion of shale underlying the site. Because the thickness of the conductive zone is small, less than 5m (15 ft) (USACE, 2000) and the distance to the nearest monitoring wells is short, approximately 225 m (740 ft), a one-dimensional transport model was selected to evaluate movement of uranium in groundwater. Activity balances for uranium are formulated in the liquid and solid phases and combined to derive a single partial differential equation for uranium concentration in the aquifer:

$$R \partial C / \partial t - D \partial^2 C / \partial x^2 + v \partial C / \partial x + R\lambda C = 0$$

where: C = concentration of uranium (Ci/m<sup>3</sup>),

t = time (yr),

D = dispersion coefficient (m<sup>2</sup>/yr),

x = position in aquifer (m),

v = average linear velocity of groundwater (m/yr),

R = uranium retardation coefficient (dimensionless), and

λ = decay constant of uranium (1/yr).

Retardation coefficient is defined as:

$$R = 1 + \{ [(1-\epsilon)/\epsilon] \rho_s K_d \}$$

where: ε = porosity (dimensionless),

ρ<sub>s</sub> = particle density of solid phase (g/cm<sup>3</sup>), and

K<sub>d</sub> = distribution coefficient for uranium (ml/g).

A computer evaluation of an analytical solution of the one-dimensional transport equation (van Genuchten and Alves 1982) was used for this analysis. The boundary condition used in solving the equation is constant concentration at the edge of the study area and the principle of superposition is used in the computer evaluation of pulse sources. For a constant concentration source, the uranium concentration in the aquifer is given by:

$$C(x,t) = (1/2)\exp\{(v-u)x/2D\} \operatorname{erfc}\{X1\} + (1/2)\exp\{(v+u)x/2D\}\operatorname{erfc}\{X2\}$$

$$u = \sqrt{v^2 + 4\lambda RD}$$

$$X1 = (Rx - ut) / 2\sqrt{DRt}$$

$$X2 = (Rx + ut) / 2\sqrt{DRt}$$

where  $\text{erfc}(X)$  is the complimentary error function of the argument  $X$  and all other variables are as defined above.

Values of parameters appearing in the model were 7.3 m/yr (24 ft/yr), 1.0, 5 m (16 ft) and  $1.5 \times 10^{-10}$  yr<sup>-1</sup> for the average linear velocity of groundwater, retardation factor of uranium, dispersivity of gypsum and decay constant of uranium, respectively. Values of dispersivity ranging from 5 to 44 m (16 to 144 ft) have been reported for fractured dolomite (Gelhar et al., 1985). The value selected as representative of the dispersivity of gypsum is the lower or conservative end of this range.

The range of possible concentrations of uranium in the environment is dependent upon the nature of the release of uranium into the contact zone aquifer. Two cases were considered to investigate the range of potential effects. In the first case, uranium was assumed to remain dissolved in the contact zone aquifer at concentration determined by the volume of injected solution,  $210 \times 10^6$  L ( $55 \times 10^6$  gal) and the mass of injected uranium, 12,000 kg (26,000 lb). This concentration is estimated as approximately  $3.9 \times 10^{-5}$  Ci/m<sup>3</sup> (39,000 pCi/L) (USACE 1999). Estimated results of movement of this pulse of material are presented in Figure 1 in the form of concentration of uranium normalized to the initial concentration. Monitoring wells B29W05D, LMW-04 and LMW-05 are located 225 (740), 320 (1,050) and 430 (1,410) m (ft), respectively, downgradient of the injection wells. The results indicate that although dispersion reduces the peak concentration, the pulse of uranium would be observed at the current time in at least one of the wells (which it is not). In the second case, uranium was assumed to precipitate at the conditions of the contact zone aquifer and to be released at the solubility determined by those conditions. Assuming a value of solubility determined using the PHREEQC geochemical model,  $2.7 \times 10^{-8}$  Ci/m<sup>3</sup> (27pCi/L), and a volumetric flow rate of groundwater consistent with the injected volume, the release would continue for a long period of time. Estimated concentrations of uranium in the environment for this type of release are presented in Figure 2. The results indicate that uranium would be observed at the monitoring wells at the current time if unretarded transport in gypsum layers occurred.

The groundwater transport analysis indicates that uranium released either in pulse or solubility-limited form would have reached monitoring wells during the 55 years that have passed since termination of use of injection wells if unretarded transport through gypsum layers occurred. Because neither uranium nor other indicators of injected solution are observed at these wells, the geochemical and geohydrologic analysis supports the premise that uranium has low solubility at conditions of the Linde site and is moving very slowly through the basal overburden and shale layers at the site. The other primary indicators were pH and solids content as indicated in Table 4 of Appendix B.

### **3.0 UNCERTAINTY ASSESSMENT OF THE LINDE PHREEQC MODEL**

An assessment of uncertainty associated with the PHREEQC modeling for Linde groundwater was conducted. Findings are described below.

Uncertainty in the estimation of solubility using geochemical models derives from a variety of sources:

- low rate of approach to equilibrium conditions in natural systems,
- incompleteness of the conceptual model of the system due to lack of knowledge regarding the system,
- error in measurement of thermodynamic properties,
- variability in the natural system, and
- error in measurement of system conditions.



The rate of approach of a precipitation reaction to equilibrium conditions depends on rates of processes whose influence are not readily quantified (Stumm and Morgan 1981). These rates processes include both chemical processes such as interaction of species directly involved in the precipitation reaction and physical processes such as transport of dissolved oxygen that influence conditions under which the precipitation occurs. Incompleteness of the conceptual model may derive from lack of knowledge of the individual solid phase controlling precipitation as well as lack of knowledge of the molecular structure of that phase. Identification of the controlling solid phase may be in error due to rate processes favoring formation of metastable phases or to lack of knowledge regarding the phase. Examples include formation of schoepite, a uranium mineral, in preference to more stable phases (Chen et al. 2000) and evolution in the understanding of the chemical composition and structure of schoepite (Finch et al. 2002). Error in the measurement or interpretation of thermodynamic data is a recognized issue in geochemical modeling, especially regarding actinides. Comparison of data on free energy of formation of uranium solids from alternate sources support values used in these calculations.

The final two sources of uncertainty, natural variability and measurement error, have been subjected to sensitivity calculations for the Linde conditions. The approach to sensitivity analysis comprised review of literature to identify important parameters (Muller and Duda 1985 and NEA 1982) and execution of solubility calculations to quantify importance of the parameters for Linde conditions. The literature review identified Eh, pH and concentration of carbonate species as the important variables. The first set of sensitivity calculations involved investigation of variation of solution composition as affecting charge balance and formation of secondary uranium aqueous species. This set of calculations varied concentration of chloride and sulfate by 4 and 7 per cent, respectively. The results indicated that estimated solubility of uranium did not change within the selected range of variation of anion concentration. The second set of calculations investigated the sensitivity of estimated uranium solubility to inclusion of uranium sulfate aqueous species. The results indicate no variation in uranium solubility with concentration of uranium sulfate. This result verifies the result of the literature review regarding important species. A final set of sensitivity calculations investigated the sensitivity of estimated solubility of uranium to concentration of carbonate species. A set of solubility calculations was performed using the highest value of alkalinity, 102 mg/L, reported in Table 21 of Appendix A of the Feasibility Study. This level is approximately twice the value reported for well LMW-06 used in the base case calculations. The results vary with Eh. Under reducing conditions, solubility of uranium is insensitive to carbonate concentration reflected the tendency of  $U^{+4}$  to form hydroxide complexes in preference to carbonate complexes. Under oxidizing conditions, uranium solubility is predicted to increase in proportion to concentration of carbonate reflecting the tendency of  $U^{+6}$  to form uranyl carbonate complexes. The conditions expected in the contact zone aquifer are reducing conditions and neutral pH implying minor sensitivity to concentration of ionic species. In addition to the above considerations, the results presented in the foregoing sections of this Appendix to the Feasibility Study demonstrate the dependence of solubility of uranium on Eh and pH.

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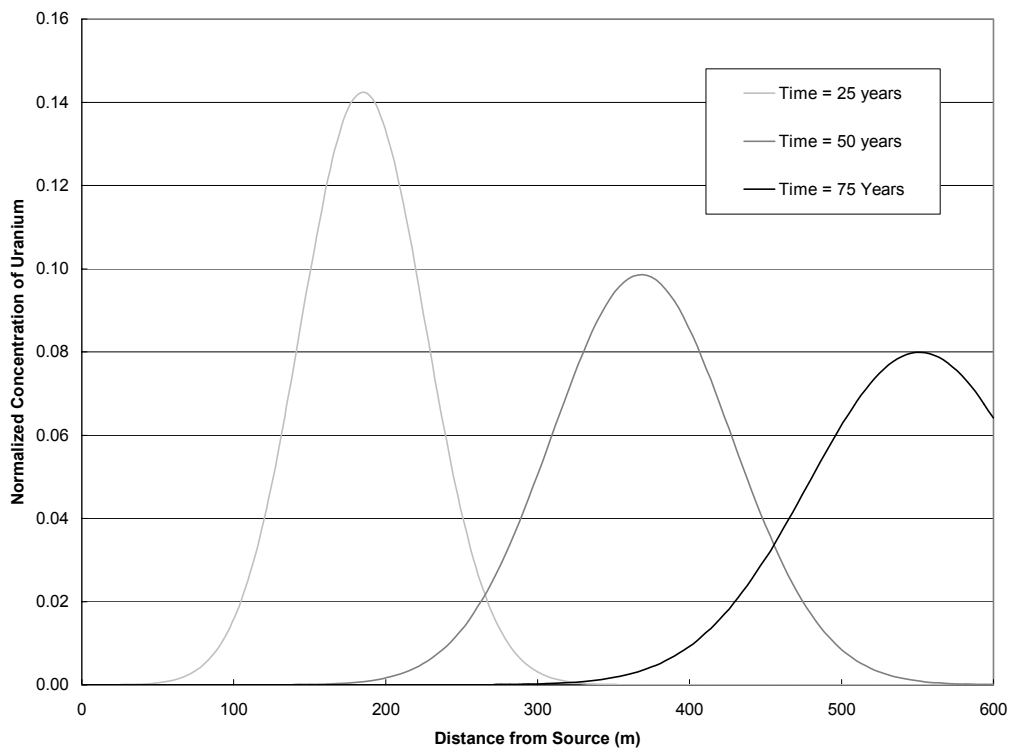
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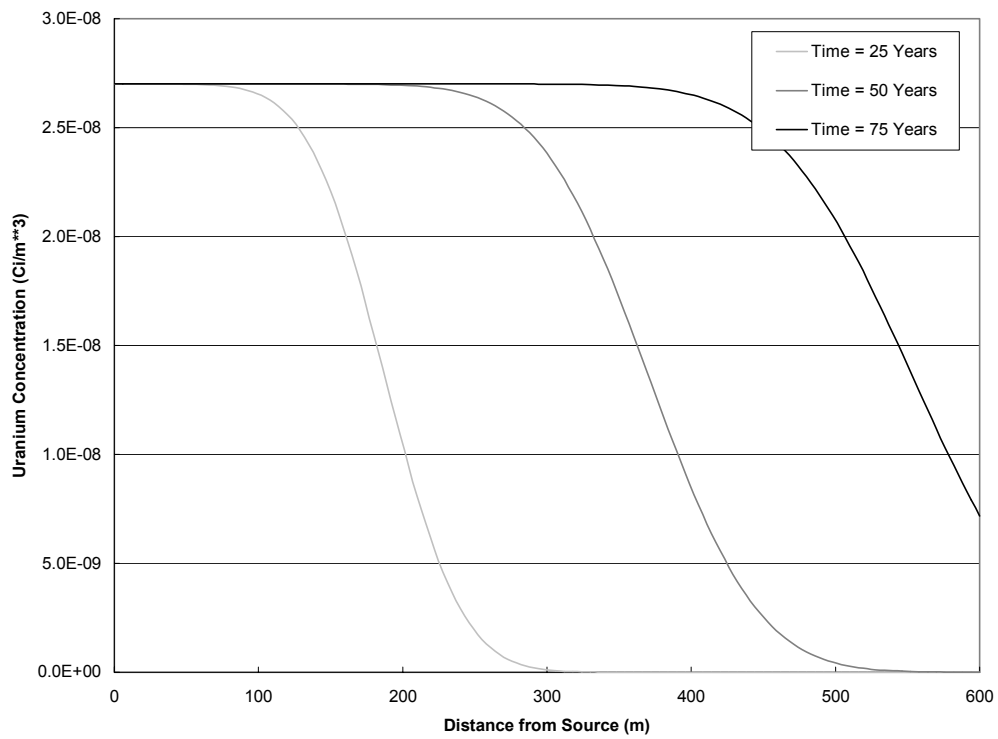
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**Figure 1. Normalized Concentration of Uranium in Groundwater for a Pulse Source**



**Figure 2. Concentration of Uranium in Groundwater for a Solubility Limited Source**

**APPENDIX C**

**REAL ESTATE PLAN**



REPLY TO  
ATTENTION OF

DEPARTMENT OF THE ARMY  
U.S. ARMY ENGINEER DIVISION, GREAT LAKES AND OHIO RIVER  
CORPS OF ENGINEERS  
P.O. BOX 1159  
CINCINNATI, OH 45201-1159

CELRD-MT-R

December 8, 2003

MEMORANDUM FOR: Commander, Detroit District, ATTN: CELRE-RE

SUBJECT: Linde FUSRAP Site, Tonawanda, New York, Groundwater Operable Unit,  
Real Estate Plan

The subject Real Estate Plan is approved subject to the following guidance.  
The easement must be acquired prior to installation of the monitoring wells.

We do not feel that it is appropriate to place construction on the property for an  
extended period without just compensation when the requirement is for a perpetual  
easement.

Regulations allow use of a right of entry for construction for limited purposes when  
acquisition of the real estate interests is contemplated within six months. In addition to  
being in violation of the regulations we believe that installation of wells for a period of  
years without payment of compensation is a violation of Public Law 91-646 and there is  
always the risk that the ownership could change prior to acquiring the real estate  
interests. This would place the Government in the untenable position of having  
construction on land without having acquired the necessary interests.

As with any other project, it is up to Engineering to define the construction requirement,  
that is, the number of wells needed. Based on the construction requirement, it is up to  
real estate to acquire the appropriate estate and certify the real estate interest available  
for construction.

This memorandum is to be made a part of the Real Estate Plan

FOR THE COMMANDER:

DOMINICK J. LIJOI  
Chief, Real Estate Division

**REAL ESTATE PLAN  
GROUNDWATER OPERABLE UNIT  
LINDE FUSRAP SITE  
TONAWANDA, NEW YORK**

**AUTHORITY**

FUSRAP was initiated by the AEC in 1974, under the Atomic Energy Act of 1954, for the purpose of remediating sites polluted with low-activity radioactive contaminants during the nation's early atomic energy program. From 1981 to 1997, the DOE managed FUSRAP. The Energy and Water Development Appropriations Act of 1998 (105 P.L. 62) transferred management of FUSRAP to the USACE in October 1997. Congress gave further directions on program management in the Energy and Water Development Appropriations Act of 2000 (106 P.L. 60) which required USACE to follow CERCLA (42 U.S.C. 9601, et. seq.) and authorized the acquisition of real estate interests where necessary to achieve the objectives of approved remedial action plans.

The FS discusses two remedial action alternatives, which are No Action and Limited Action. The Real Estate Plan (REP) addresses the real estate interests the federal government needs to acquire in order to implement these alternatives.

**LOCATION**

The Linde Site is located in the Town of Tonawanda, New York, a suburb of Buffalo, New York. The 135-acre Site is owned by PRAXAIR, Inc. a worldwide manufacturer of industrial gases and a Fortune 500 company. PRAXAIR serves a wide range of industries including food and beverages, healthcare, semiconductors, chemicals, refining, primary metals and metal fabrication, as well as other areas of general industry. The Tonawanda location is a major research and development facility for PRAXAIR, Inc. Figure 4 shows the Site boundaries and the location of current and proposed groundwater wells.

The Site is zoned as a P-S Performance Standards Use District. This zoning designation encourages and allows the most appropriate current use of the land, as well as, approaching commercial and industrial uses, unhampered by restrictive classifications. Residential development is allowed, if such development currently abuts the Site. In fact, residential housing and an elementary school currently abut the Site's west side. The Site's anticipated future land use, however, is industrial/commercial given past and present uses including, the Site's massive industrial infrastructure of office buildings, fabrication facilities, warehouse and storage areas, parking lots, utility tunnels and extensive network of storm and sanitary sewers.

**REMEDIAL ACTION OBJECTIVES**

Contamination of the Site's deep groundwater occurred between 1944 and 1946 when seven wells were used to inject 55 million gallons of liquid waste into the deep aquifer. This resulted in the discharge of an estimated 12,000 pounds of uranium oxide at depths of 90 to 150 feet. Radium was, also, present in the waste. During the same time frame, contamination of the

shallow groundwater occurred from leaching of surface soil contaminants.

The Site's groundwater in its natural state is not suitable for use as drinking water. The groundwater in the deep aquifer contains high levels of total dissolved solids and salinity. The shallow aquifer has low hydraulic conductivity causing limited potential yields. These findings preclude the use of the National Primary Drinking Water Regulations as the ARAR for Site's Groundwater Operable Unit. Other potential ARAR's are rejected for the same reasons. The selected ARAR is the standards found in Subpart A of 42 CFR Part 192 promulgated to implement the UMTRCA.

Groundwater testing in 2001 of both the shallow and deep groundwater reveals findings below the ARAR at the point of compliance, which are the property lines of the Linde Site. Elevated findings, however, are found in two shallow interior test wells and the seven old injection wells. Modeling, including geochemical modeling, indicates the contaminants in the deep groundwater are unlikely to migrate beyond the Site's boundaries. The slightly elevated findings in the shallow groundwater, also, are unlikely to exceed the ARAR in the future, since leaching from Site soils cause this contamination and there is an extensive ongoing program of soil remediation. The soil remediation has resulted in removal of thousands of tons of radiological contaminated material from the Site.

Since compliance with the ARAR is considered protective of human health and environment under CERCLA, active groundwater remediation or containment alternatives are eliminated because of implementability considerations and need. The alternatives of No Action and Limited Action are considered, however, since the numeric thresholds of the ARAR are exceeded in limited locations on the Site and there are no current Land Use Controls (LUCs) in place precluding use of Site groundwater.

Under the No Action alternative the groundwater is left as is and monitoring not conducted. The Limited Action alternative requires ongoing monitoring and LUCs to preclude use of Site groundwater and prohibit drilling new wells and using existing wells. The ability to monitor and restrict use needs to remain in force for 1,000 years.

### **LANDS REQUIRED FOR IMPLEMENTATION OF ALTERNATIVES**

The No Action alternative requires no lands for implementation.

The Limited Action alternative requires land for installation of monitoring wells and access to these wells. The prohibition on use of Site groundwater and either the drilling of new wells or use of existing wells require the implementation of various LUCs. To be effective, LUCs must be layered to ensure long-term maintenance of the remedy. For example, although a zoning use consistent with the remedy changes to an inconsistent use, the layering of other LUCs, such as a restrictive easement or a deed notice, prevents land use inconsistent with the remedy. Likewise, inconsistent land use might be prevented when a potential purchaser discovers, during a routine environmental audit, that the Site appears on various lists of contaminated properties maintained by the federal, State and local governments. Such a discovery will force the purchaser to engage in further due diligence to determine, if use of the Site is restricted.

Some LUCs, such as deed notices, local well drilling permits, and ordinances prohibiting groundwater use, do not require acquisition of a real estate interest. The success of these LUCs depends, however, on the cooperation of the current Site owner and local governments, since the federal government is unable to enforce these controls. In order for the federal government to assure achievement of the Limited Action alternative, it needs to acquire a real estate interest. This type of LUC allows enforcement, by the federal government, of restrictions on groundwater use and the prohibition against either drilling new wells or using existing wells. If necessary, this type of LUC can be enforced through court action.

Although the development and approval of a Land Use Control Plan for the Groundwater Operable Unit Linde FUSRAP Site will occur after execution of the Site's Record of Decision, the possible acquisition of real estate interests by the federal government needs to be developed during the project feasibility phase. This allows recognition of cost and schedule impacts of real estate acquisition activities.

## **ESTATES**

The federal government must acquire sufficient real estate interests from the Site owner, PRAXAIR, Inc., to install, operate, and maintain 14 monitoring wells and restrict groundwater use on the entire 105 acre Site. To accomplish these objectives a non-standard permanent easement, i.e., a Monitoring Wells and Groundwater Restrictive Easement, has been approved for implementation of the Groundwater Operable Unit Linde FUSRAP Site Tonawanda, New York. The easement deed will include the right of reasonable access to the monitoring wells.

The approved non-standard easement estate is as follows:

### **MONITORING WELLS AND GROUNDWATER RESTRICTIVE EASEMENT**

A perpetual and assignable right and easement in the land described in Schedule A, to locate, construct, operate, maintain, alter, repair, replace and/or remove monitoring wells and appurtenances thereto, for monitoring contamination in water and performing any other such work, which may be necessary and incident to the Government's groundwater remediation of said lands under the Groundwater Operable Unit, Linde FUSRAP Site, Tonawanda, New York Project, together with the right to post signs and prohibit the Grantor, its successors and assigns from using the groundwater, from pumping water from any existing wells, using these wells or the water therein in any way whatsoever, and installing, sinking, digging, and drilling any new water wells; reserving, however, to the Grantor, its successors and assigns all such rights and privileges as may be used without interfering with or abridging the rights and easement hereby acquired; subject, however, to existing easements for public roads and highways, public utilities, railroads and pipelines.

## **VALUE OF LANDS**

The estimated value of the permanent Monitoring Wells and Groundwater Restrictive Easement,



required for implementation of the Limited Action alternative, is seventy-five thousand dollars (\$75,000). A gross appraisal, with an effective date of October 17, 2003, determined this amount. In determining value, the Market Sales Comparison Approach was used. After the fee value of the Site was determined, in this case twenty-two thousand dollars (\$22,000) per acre, the extent of the right taken was calculated. The appraisal found the restriction to groundwater use was 2.5% of fee and the monitoring well locations, which requires a 24x24 foot area for each well, 50% of fee. The appraisal, also, added a 25% contingency on the fair market value determination.

## **ENVIRONMENTAL**

The Site remediation is implemented under CERCLA. It has been performed in compliance with all environmental requirements. Extensive investigation of the Site's history and current condition has been performed. Additional investigations are likely needed to comply with the stipulations for developing the Record of Decision.

## **MISCELLANEOUS**

The REP must include discussion of a number of topics, which are unrelated to the remedy for the Groundwater Operable Unit Linde FUSRAP Site Tonawanda, New York. The following is a brief discussion of these topics. The property is neither owned by the federal government nor been provided for another federal project. It, also, is not subject to the navigation servitude. No present or anticipated mineral activity is within the project area. The project will not require displacement of persons or businesses. There are no historic properties within the proposed project area. There are no cemeteries or public facilities within the area requiring relocation. In addition, plans and specifications do not identify any relocation of public utilities or roadways.

## **REAL ESTATE MANAGEMENT PLAN**

Real Estate Division will monitor the real estate requirements throughout implementation of Site remediation of the Groundwater Operable Unit. Given the changing requirements typical in environmental remediation projects, additional real estate interests may be needed. As necessary, this REP plan will be supplemented to allow acquisition of additional real estate interests to implement the selected remedy.